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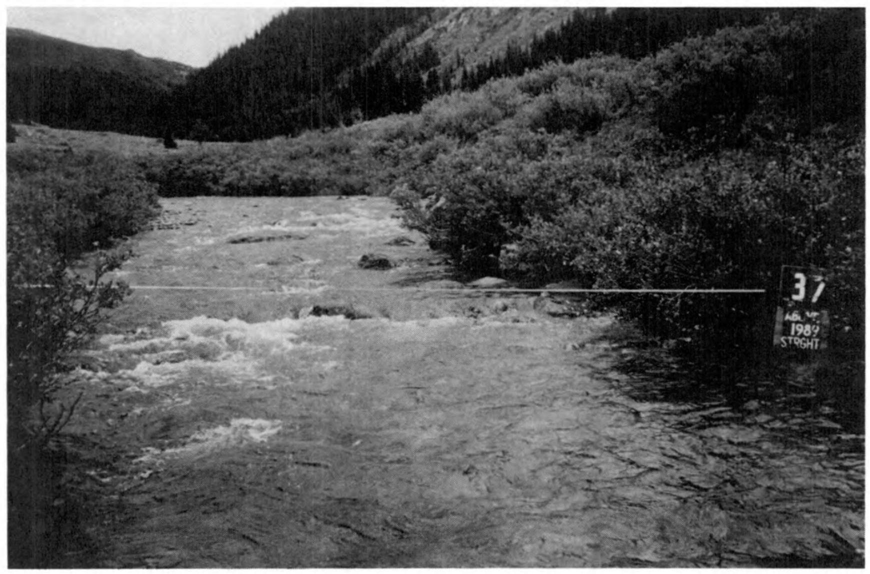
Stream Systems
Technology Center
General Technical
Report RM-GTR-270

Summary of Technical Testimony in the Colorado Water Division 1 Trial

Nancy Gordon

Lost Man Creek Above Diversion



Lost Man Creek Below Diversion

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Abstract

The Colorado Water Division 1 Water Rights Trial was one of the most significant federal reserved instream flow water rights cases to occur since the Supreme Court of the United States ruled in the case of United States v. New Mexico in 1978. This document summarize the large amount of technical data and information pertaining to the disciplines of geomorphology, hydrology, and sediment transport mechanics compiled and presented to the judge during the Water Division 1 trial. The summary discusses channel formation and maintenance as viewed by scientists with differing opinions and allows readers to form their own judgment about the technical merits or validity of these differing viewpoints.

Key Points for Managers to Consider in Approaching Future Adjudications

- **Anticipate and strategically plan for adjudications.** Prioritize resource values and concerns. Identify potential conflict, and determine the availability of data to support instream flow claims. Focus efforts on high priority sites that have the potential for a strong set of facts that will sustain your claim.
- **Make the necessary commitments of dollars and personnel** consistent with strategic needs.
- **Develop a study design** for the adjudication and begin data collection as early as possible.
- **Identify and involve appropriate research personnel and other technical experts** early in the process to assist with study design, data collection, data analysis, and validation of technical theories to support instream flow quantifications.
- **Involve the Office of General Counsel** in all phases of planning.
- **Use standard data collection and analysis techniques** and place special emphasis on quality control. Data must be able to withstand the scrutiny of other experts and the court. Remember, the United States bears the burden of proof in most adjudications.
- **Inform the public** that instream flows are a non-consumptive use of the water, that is, water needed for instream flows remains in the channel and is available for downstream uses by others once it leaves the National Forest. The conflict between instream flows and other uses of water is often more a matter of perception than reality. Emphasize that the public derives multiple benefits from water that is left in the stream.
- **Seek technical advice** from the Stream Systems Technology Center in Fort Collins.

Source: Stream Systems Technology Center

Prepared in support of the National Stream Systems Technology Center mission to enable land managers to "secure favorable conditions of water flows" from our National Forests.

USDA Forest Service
General Technical Report RM-GTR-270

September 1995

Summary of Technical Testimony in the Colorado Water Division 1 Trial

Concerning the application for water rights of the United States of America for reserved water rights in the Platte River, in Boulder, Park and Teller counties

Judge Robert A. Behrman presiding

Case held at Greeley, Colorado from January-December, 1990

Prepared for:

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Contents

Preface

The Colorado Water Division 1 (WD1) Water Rights Trial was one of the most significant federal reserved instream flow water rights cases to occur since the Supreme Court of the United States ruled in the case of United States v. New Mexico in 1978. The WD1 case is unique in the large amount of expert testimony presented and in how the Judge evaluated the testimony and evidence in reaching his decision.

We believe that this synthesis of case testimony provides important information regarding fluvial geomorphology, hydrology, and related subjects. More importantly, readers will learn that consistency, quality control and testing of approaches are essential in describing the minimum instream flow necessary to sustain a stream channel. They will also find that the purposes of the federal reservation vitally influence the decision. In having a mandate for conservation and use, the Forest Service must consider how the instream flow regime benefits downstream users that rely on the National Forests for their water supply.

THE PURPOSE OF THIS PUBLICATION IS TWO-FOLD

First, it serves to summarize the large amount of technical data and information pertaining to the disciplines of geomorphology, hydrology, and sediment transport mechanics compiled and presented to the judge during the Water Division 1 trial. Some of the data from fluvial study sites established by the Forest Service in anticipation of the trial are presented. In addition, the summary discusses channel formation and maintenance, as viewed by scientists with differing opinions, and allows readers to form their own judgment about the technical merits or validity of differing viewpoints.

Secondly, this publication has been prepared to help managers and scientists understand how one experienced Water Court Judge viewed the testimony and technical evidence presented. By highlighting some of the strengths and weaknesses, we can learn important lessons. This knowledge will help make future cases more understandable and compelling.

THE TECHNICAL SUMMARY IS PREPARED IN TWO PARTS

1. The **Executive Summary** is intended primarily for managers. This short document summarizes the history of federal reserved water rights, outlines the major issues argued in the case, and presents the court's decision.

2. The **Summary of Technical Testimony in the Colorado Water Division 1 Trial** is intended for technical specialists and others interested in a detailed understanding of the case and its technical arguments. It is divided into 8 sections:

Section 1.	Overview of the Water Division 1 Case
Section 2.	History and Policy Issues
Section 3.	Theories on Channel Formation and Maintenance
Section 4.	The Character of Streams in Water Division 1
Section 5.	Field Data Collection and Analysis
Section 6.	Sediment Transport in Mountain Streams
Section 7.	The United States Quantification Procedure
Section 8.	The 1990 Alternative Quantification Procedure

In Water Division 1, the Department of Justice, representing the Forest Service and acting on behalf of the United States, filed federal reserved water right claims for instream flows based on the Organic Act interpretation of favorable conditions of water flows. These claims to instream flows were challenged by the State of Colorado and water conservancy Districts in northern Colorado that divert water from National Forests.

The United States claimed it needed to keep a certain amount of water in National Forest streams to protect stream channels and timber. Opponents feared future development of water storage projects within the National Forests would be nearly impossible if channel maintenance instream water rights were granted.

The case, which started in 1976, went to trial in 1990 in District Court, Water Division 1, of the State of Colorado. Closing arguments were made in March 1992 and Judge Robert Behrman issued a "Memorandum of Decision and Order" on February 12, 1993.

During the one year duration of the trial, Judge Behrman heard testimony from 49 expert witnesses and evaluated 1,500 exhibits. The case was unusual in that more than one half of the testimony dealt with the highly technical sciences of hydrology and geomorphology.

In his ruling, Judge Behrman recognized that reserved water rights of the United States include channel maintenance purposes. However, with regard to specific claims, Judge Behrman concluded:

- "The applicant (United States) has failed to show that the reserved water rights claimed are necessary to preserve the timber or to secure favorable water flows for private and public uses under state law."
- "The applicant (United States) has failed to establish the minimum amount of water needed to ensure that the purposes of the reservation of the national forests in Water Division 1 will not be entirely defeated."

The court, however, granted the United States reserved water rights for administrative sites and fire-fighting purposes and suggested that the Forest Service could use its special use permitting authority to control diversion within the National Forests in lieu of obtaining water rights.

DISCLAIMER

This document was prepared by Nancy Gordon of Engineers Inc. under contract to the Stream Systems Technology Center, Rocky Mountain Forest and Range Experiment Station. The author did not participate in the case, attend any of the court proceedings, or have in-depth knowledge of Forest Service channel maintenance procedures prior to the contract. Information used to prepare this summary was obtained almost exclusively from a reading of the court reporter's transcripts of the trial (more than 15,000 pages) and examination of trial exhibits.

Any interpretation or representations of Forest Service policy, the legal positions of the United States, the State of Colorado, or others involved in the trial, are those of the author and do not necessarily reflect the policies, viewpoints, positions, or interpretations of the United States, the Forest Service, or others.

Readers will notice that some of the illustrations lack the high quality of original art work usually found in Rocky Mountain Station publications. We purposely chose to use the original court exhibits with only slight editing. We want the reader to have an impression of what was presented and how it was illustrated rather than precise details. Our goal is to maintain high fidelity with the case as presented and to avoid introducing changed or different material than what was offered in court.

ABOUT THE AUTHOR

Nancy Gordon is presently an Engineer/Hydrologist for Engineers Inc., a consulting firm in Silver City, New Mexico. She is also an Assistant Adjunct Instructor at Western New Mexico University and has a B.S. in Botany from Northern Arizona University and a M.S. in Civil Engineering with emphasis in Hydrology from New Mexico State University. She is senior co-author of the book, *Stream Hydrology: An Introduction for Ecologists*, with Thomas McMahon and Brian Finlayson.

Section 1.
Overview of the WD1 Case

This case was part of an adjudication process in which the U.S. was claiming water rights for the Arapahoe, Pike, Roosevelt and San Isabel National Forests within Water Division 1 (WD1) in Colorado. The National Forests were located on the east side of the Continental Divide, and contained the headwaters of the Laramie and South Platte Rivers (fig. 1).

Opposers included the State of Colorado, City and County of Denver, and several irrigation districts which all had concerns about the potential effects of the U.S.'s claims on existing water rights and on the development of future water supply projects within National Forests. The U.S. also entered into stipulations with a number of water users who didn't participate in the trial. These included the cities of Fort Collins, Greeley, Longmont and Thornton. In its settlements, the U.S. subordinated its claims to those of the other water users (i.e. gave them seniority). Appendix A

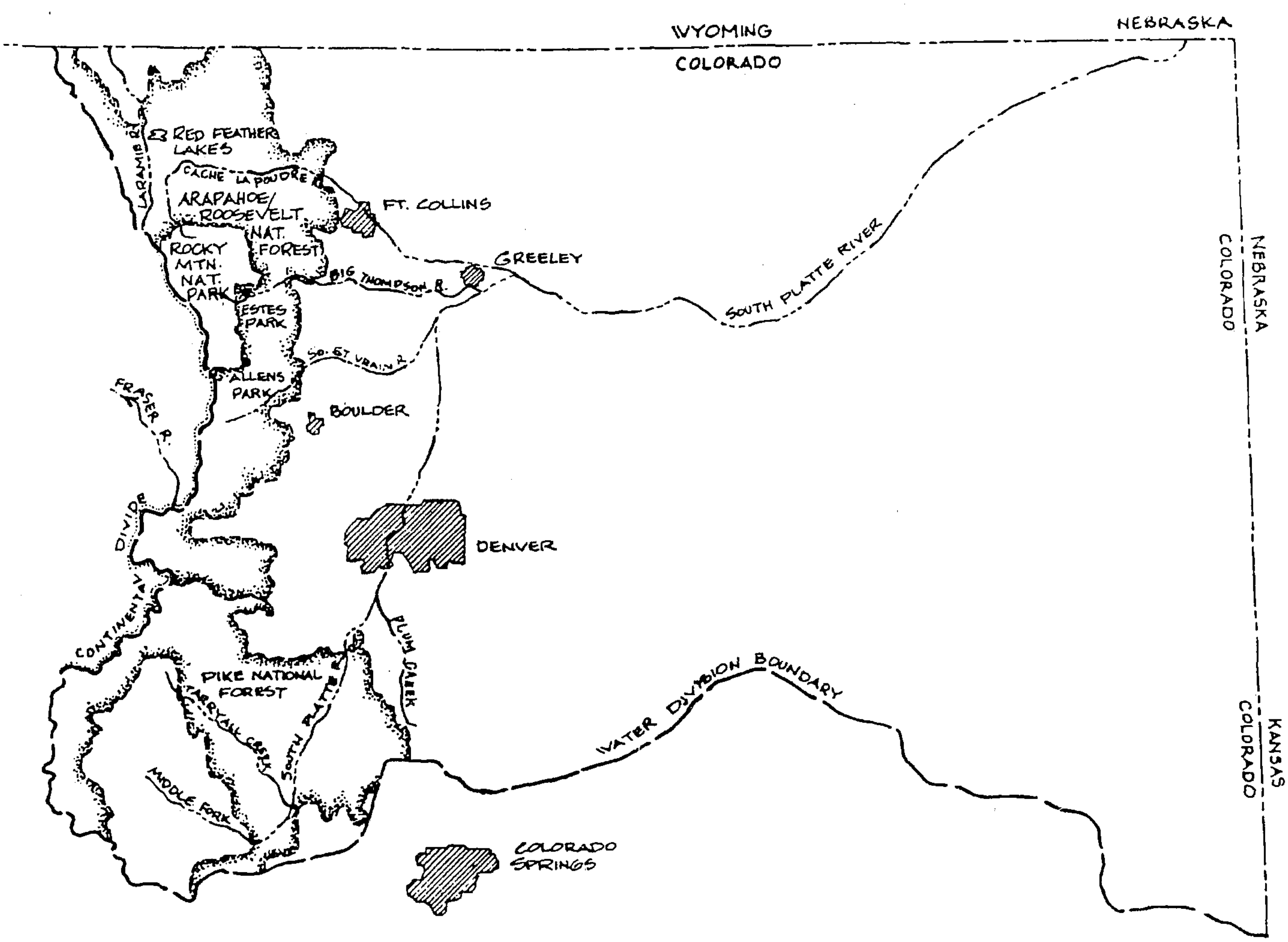


Figure 1.—Location map for Water Division 1 in northern Colorado.

contains information on participants in the WD1 trial.

In its application, the U.S. claimed federal reserved water rights for these purposes:

- fire fighting (an unlimited amount),
- administrative sites (not more than 10 acre-feet per site per year and not more than 1 site per 100,000 acres of national forest, with actual quantities to be determined when the need arose),
- instream flows for channel maintenance (including baseflow, bankfull and rise/recession components, with the total amount claimed averaging 50% of average annual runoff).

Water rights for the first two purposes met little opposition and were approved by the Court. In the judge's words, the third purpose was the focus of "a lengthy trial" in which "a vast number of exhibits were introduced" (2/12/93 Decision, p. 1).

Appendix B provides a brief chronology of the WD1 case. The U.S. originally filed its applications for water rights in WD1 in 1976. The case was not tried until 1990, and the Court's final decision was issued February 12, 1993. The U.S. spent an estimated $10 million on its case and the opposers' costs also ran into the millions of dollars. The case was important in that its outcome would influence future adjudications on National Forest lands not only in Colorado but across the country (Walch 1/8 at 4-5). The U.S. had never before been awarded reserved water rights for instream flows on National Forest lands (Woodward 1/8 at 71).

HISTORY OF FEDERAL RESERVED WATER RIGHTS

The history of the WD1 case was strongly influenced by ongoing legislation concerning federal reserved water rights; in fact, this case would play a key role in defining these rights on National Forest lands.

Reserved water rights on Federal lands exist by implication rather than by statute. In the 1963 Arizona v. California case, the court referenced the Winter's case of 1908 which defined the Reserved Rights Doctrine. In the Winter's case, which involved an Indian reservation, the Court stated that when the U.S. reserved lands for a particular purpose, there was also sufficient water reserved to meet the purposes of that reservation. The water rights had a priority date as of the date of reservation. The U.S. was still required to identify and quantify those rights in state courts. In the WD1 case, the U.S. maintained that federal reserved water rights in WD1 were obtained when lands were set aside as public forest reservations during the period 1892-1916 (U.S. brief 9/9/91 at 1).

The 1978 U.S. Supreme Court decision in U.S. v. New Mexico (the "Mimbres Decision") concluded that water could be reserved for National Forests:

> *"only where necessary to preserve the timber or to secure favorable water flows for private and public uses under state law" (2/13/90 Decision, p. 2-3)."*

This decision was based on the Supreme Court's interpretation of the Organic Act which defined the purposes for which forest reservations could be made. Section 1 of the Organic Act, dated June 4, 1897, contained this statement (1/8 at 7):

> *"No public forest reservation shall be established except to improve and protect the forest within the boundaries or for the purpose of securing favorable conditions of water flows and to furnish a continuous supply of timber for the use and necessities of the citizens of the United States."*

As a result of the Mimbres decision, the WD1 applications were amended in 1984 to limit claims to the amount required to secure favorable conditions of water flows in streams, along with claims for administrative sites and fire-fighting which were deemed necessary for both timber and water protection. This was the U.S.'s first attempt to quantify instream flows for channel maintenance in a courtroom setting.

In a subsequent case, U.S. v. Jesse (1987), the Colorado Supreme Court concluded that the U.S. could claim instream flow rights to achieve the purposes of the Organic Act (2/12/93 Decision, p. 1). In the Jesse case, the Court had stated that for each federal claim for reserved water rights, the trier of fact must (1/8 at 10):

- "examine the documents reserving the land from the public domain and the Organic Act,
- determine the precise federal purposes to be served by such legislation,
- determine whether water is essential for the primary purposes of the reservation, and finally,
- determine the precise quantity of water necessary to satisfy such purposes."

In the WD1 case, both sides presented evidence addressing each of these areas.

Work to further refine the WD1 claims was accelerated after the Jesse case. After consultation with renowned experts in fluvial geomorphology, the U.S. developed its position that the term "favorable conditions of water flows" referred to the timing and magnitude of flows necessary for maintaining channels so they would not become clogged with sediment and encroaching vegetation, which would reduce their capacity for passing flood flows. Without channel maintenance flows, "unfavorable conditions" of accelerated streambank erosion, channel instability and accelerated deposition of sediment in reservoirs could occur. U.S. teams carried out an extensive field data collection and analysis program in 1988 and 1989 using a refined claim methodology. Another amended application was filed in 1989. This application and methodology were the basis for the WD1 trial which began in January 1990.

ISSUES IN THE WD1 CASE

The U.S. had the burden of proof in this case. During the trial, expert witnesses argued both sides of the historical evidence for channel maintenance flows, and about the technical theories and methodologies used for forming the claims. Data collection was also continued during the course of the trial in the 1990 field season. The U.S.'s procedures for claiming instream flows were outlined in Chapter 30 of a Forest Service Handbook; however, the actual methodology was continuously evolving. The WD1 claims represented a departure from procedures given in the version of Chapter 30 which was in place at that time. This was one of the main points of contention made by the opposition. A brief summary of issues in the WD1 case is presented in Table 1.

Table 1.—Summary of major issues argued in the Water Division 1 case.

Issue	U.S. position	Opposition position
Reserved water rights	The U.S. was entitled to water under the Reserved Rights Doctrine for channel maintenance purposes.	The U.S. didn't have a reserved water right for channel maintenance flows. It didn't need water rights because it had other mechanisms for controlling diversions such as special use permits.
Meaning of "favorable conditions of water flow"	Forest and channel conditions which would ensure conveyance of water to valleys below without excessive flooding, erosion or sedimentation.	Streamflow hydrographs which matched demands of irrigation and domestic users, e.g. by using reservoir storage to store spring runoff for use later in the summer.
Form of the U.S. claim hydrograph	The amounts claimed were the minimum amount needed and were non-consumptive. They left an average of 50% of the annual runoff for diversion. The 1990 claims addressed many of the criticisms given by opposition witnesses.	Because of variability in the claim methodology and in quantifying sediment load in the streams, the U.S. claims were for more water than what was really needed. The 1989 claims didn't match the actual runoff hydrographs, so they didn't even accomplish the purposes of channel maintenance.
Injury to other water users	Injury was not really an issue. Allowances had been made for other water users in the structure of the claims, the location of quantification points, and through settlements with water users.	Injury was a main issue. The U.S. claims would restrict diversion of water during the critical spring runoff period. The error bands on the U.S.'s claims were significant amounts of water. Colorado's water rights had developed over a long period of time without allowing for a senior U.S. water right, and to impose it now was injurious.
Bankfull flow level	This level had a geomorphic definition as the level of the present floodplain, identified in the field by the tops of bars or changes in vegetation or substrate.	The physical top of the streambanks, identified by a break in slope in the cross-section profile.
Adjustable nature of channels	The channels would adjust to frequently occurring flows. Bankfull flow was the effective discharge which controlled channel shape.	Because channel boundaries contained large boulders transported by megafloods or glacial action, and bedrock, log jams and beaver dams, they would not adjust to bankfull discharge.
Sediment transport	The mountain streams transported a substantial amount of sediment which would accumulate without the channel maintenance flows. Bedload was hydraulically-controlled.	The streams transported minimal amounts of sediment. There was less material available than what the stream could carry (i.e. the streams were supply-limited).
The effect of diversions	Measurements taken above and below diversions generally showed a decrease in channel size and an increase in vegetation downstream. Some downstream channels had almost disappeared entirely.	The U.S.'s measurements were biased. The effect of diversions was overwhelmed by other factors such as changes in geology and slope. Channels downstream of 100-year old diversions did not show adverse impacts.

THE COURT'S DECISION

In his final decision on February 12, 1993, Judge Behrman concluded that:

- The U.S. failed to show that the reserved water rights claimed were necessary to "preserve the timber or to secure favorable water flows for private and public uses under state law."
- The U.S. failed to establish the minimum amount of water needed to ensure that the purposes of the national forests would not be entirely defeated.

He ruled that reserved water rights for fire-fighting and administrative sites were necessary, and ordered decrees granting an unlimited amount of water for fire-fighting and an amount for administrative sites as explained earlier. The 1990 amendment was denied. Other than the decrees for water rights for fire-fighting purposes and administrative sites, the U.S. applications were denied (2/12/93 Decision, p. 32-33).

In his ruling, the judge concluded that the Organic Act and other legislation had regarded irrigation and domestic use as the principle purpose for maintaining favorable conditions of water flows. "Favorable conditions" were those which evened out streamflows for those uses, and included reservoir storage. The U.S.'s assertion that its claims were nonconsumptive did not take into account the effect of timing; i.e. most of the water available for junior storage was during the spring runoff period, which would be most affected by the U.S. claims.

The judge also ruled that the U.S. had "broad powers" to regulate diversions within national forests and that the permitting system had been adequate for over 100 years. He did not see any limitation in the Organic Act restricting uses of diverted water, and said, "diversion for use outside the forests seems clearly to be anticipated" (Decision, p. 19). He believed that the streams in WD1 would not dry up without the claims because of downstream senior demands. Finally, he concluded that it was inconceivable that Congress had intended for reserved water rights to interfere with use for irrigation and domestic purposes (Decision, p. 20).

According to Walch (pers. comm., 8/3/94), the judge did effectively rule that the Forest Service had reserved water rights for channel maintenance purposes. Walch based this interpretation on these statements in the Court's Decision (p. 20):

> *"It is this court's view that channel maintenance is necessary to effectuate a purpose of the national forests. But such maintenance is required only to a reasonable degree consistent with both the requirements of stream flows and the necessities of efficient irrigation and domestic use."*

and (p. 13):

> *"Different considerations may apply to cases where there is a potential for diversions at points above the national forests or in inholdings. Those matters should be resolved in applications limited to such circumstances. In this way the matters can be resolved in a manner suited to the specific requirements of each situation."*

Therefore the Forest Service could make future applications for federal reserved water rights for instream flows where diversion of water from streams in private inholdings might affect streams on surrounding National Forest lands. For diversions located within Forest lands, the Forest Service would have to use special permitting or other methods of control.

Section 2.
History and Policy Issues

THE ORGANIC ACT AND ITS HISTORIC SETTING

The WD1 case involved the interpretation of two federal statutes (2/12/93 Decision, p. 1-2):

- The Creative Act of March 3, 1891 which authorized the president to reserve national forests
- The Organic Administration Act of June 4, 1897 which defined the purposes for which reservations could be made

In the case, both sides called on historians and policy experts to testify about the circumstances surrounding the development of these acts. The U.S.'s objective was to connect these Acts to the conservation movement. The opposition emphasized legislation pertaining to irrigation, and evidence which showed a historical deference to state water laws. Both sides agreed that there was a close relationship between forest protection, water flows, and irrigation. The U.S. maintained that Congress' intent at the time was to protect mountain watersheds and stream channels in order to convey water to the "fertile valleys below" (Wengert 8/14 at 70). The opposition argued that Congress only intended to protect the forest cover, and had promoted diversion and storage of water even if it meant sacrificing the streams.

GENERAL ATTITUDES OF LATE-1800'S AND EARLY-1900'S SOCIETY

U.S. witnesses described the late 1800's as the end of the American frontier and the beginning of a period when society was starting to realize resources were not inexhaustible and were demanding protection of resources from exploitation - "use but not abuse." George Perkins Marsh, author of the 1864 book, "Man and Nature," was credited with developing the commonly-repeated metaphor that watersheds acted like "sponges" to absorb water and release it slowly to streams. He used the words "harmony of nature" and "condition of equilibrium" to refer to the undisturbed state of nature. It was his view that removal of timber cover caused flashier floods, lower summer flows, and the filling of streambeds with sediment which could cause them to change course (Nash 1/9 at 85-9).

Both President Teddy Roosevelt and the first chief of the Forest Service, Gifford Pinchot, had read Marsh's book. They were early leaders of the conservation movement which began during this era. Pinchot was said to have coined the word "conservation" about 1907. He is often quoted as saying:

> *"Conservation means the greatest good to the greatest number for the longest time" (Nash 1/9 at 43-44; 56).*

The opposition painted a different picture of this era, pointing to major struggles of East vs. West, national vs. local interests, and development vs. preservation. The West was seen as the "land of opportunity," with the government promoting western development through its support for railroads, irrigation projects, land grants, and the Homestead Act of 1862. Because their livelihoods depended on irrigation, early settlers had great concerns about access to water, and they supported water supply projects.

Historians also called the last quarter of the 19th century the "Gilded Age" to describe a gold overlay covering something basically rotten at the core. A superficial image of prosperity had been gained as a result of general corruption in business, oppression of labor and the American farmer, and resource devastation. McCarthy, an opposition witness (3/20 at 24-25), expressed the opinion that conservation was just another way of maintaining the East's colonial power over the West by controlling its resources. After a major depression in 1893, a period of revolt against Eastern policies ensued, characterized by the organization of farmer's alliances, mining wars, and the anti-conservation movement composed of stockmen, homesteaders, miners, and western politicians. Colorado was right in the mainstream of the anti-conservation movement.

It was within this context that the 1891 and 1897 Acts were written.

THE 1891 CREATIVE ACT AND THE 1897 ORGANIC ACT

Until 1891, federal policy was to give away public land to settlers or to sell it off at a low price. The 1891 Act reversed this policy and allowed the

President to withdraw lands to be retained permanently as a legacy of the people of the United States. Between 1871 and 1897, there were approximately 200 bills in Congress dealing in some way with forests or public land.

The origins of the 1891 Act were somewhat obscure, although previous legislation had mentioned protection of trees and undergrowth from fire and axe, the importance of forests for regulating flows and preventing devastating floods, and their influence on climate, temperature and public health. The "Creative Act" or "Forest Reserve Act" which was approved March 3, 1891, stated:

> *"That the President of the United States may, from time to time, set apart and reserve, in any State or Territory having public land-bearing forests, in any part of the public lands wholly or in part covered with timber or undergrowth, whether of commercial value or not, as public reservations, and the President shall, by public proclamation, declare the establishment of such reservations and the limits thereof" (Wengert 8/13 at 33).*

A major limitation of the 1891 Act was that it did not specify the purposes of the reservations or how they were to be used. Wengert, an opposition witness (8/13 at 31-33), pointed out that the above language was from Section 24 of a larger act called the General Revision Act which dealt with many public land policies such as reservoir sites and right-of-way through federal lands for irrigation canals, etc. He interpreted this to mean that Congress expected the development of natural resources within forest reserves, subject to government approval of right-of-way.

The General Land Office (GLO) of the Department of the Interior was originally in charge of the forest reserves. Its first priority was to reserve all forested public lands where timber was not absolutely required for development. Lands deemed most important were those:

> *"at the headwaters of rivers and along the banks of streams, creeks and ravines, where such timber or undergrowth is the means provided by nature to absorb and check the mountain torrents, and to prevent the sudden and rapid melting of the winter's snows and the resultant inundation of the valleys below, which destroy the agricultural and pasturage interests of communities and settlements in the lower portions of the country" (Wengert 8/13 at 38-9; Steen 1/11 at 107).*

However, it was the Department of the Interior's interpretation that the lands withdrawn were to be ***inaccessible to the public*** for any purpose. This resulted in considerable controversy, and a series of bills were subsequently developed in an attempt to define the purposes, uses, and management of the reserves. The 1897 Act was the culmination of these efforts.

By 1897, Presidents Harrison and Cleveland had reserved approximately 17 million acres of land under Section 24 of the 1891 Act. In 1896, a National Academy of Science Commission, which included Giffort Pinchot, gave recommendations to President Cleveland on additional forest reserves. Without consulting or notifying anyone, President Cleveland decided to celebrate George Washington's birthday (February 22, 1897) by proclaiming all of the forest reserves recommended by the Commission. This amounted to about 20 million acres (none of which were in Colorado).

Due to anger over Cleveland's "midnight reserves," a number of amendments and other acts were introduced in an attempt to negate what Cleveland had done, including a bill which was sent to Cleveland to sign the day he was to leave office and McKinley was to be inaugurated. Cleveland didn't sign it and left office, having little support from either Republicans or Democrats by that time. President McKinley's first act was to hold a special session of Congress to prevent the rescinding of Cleveland's proclamation. There was much discussion and debate documented in Congressional records. In the process, compromises were worked out on the language which would finally be contained in the June 4, 1897, Organic Act - to mollify those opposed to reservations in general and the President's action in particular. As a result of negotiations on the Organic Act, none of the 37 million acres reserved to date were canceled after the Act was passed.

The 1897 Act was perceived as a clarification of the 1891 Act. The 1891 Act allowed the President to set aside forest reserves; the 1897 Act specified what they were for. The "Organic Act" was actually an amendment to an appropriation measure for the Department of the Interior. It contained provisions for returning lands more suited to agriculture to the public domain, for protecting the forest cover from fire and depredation, and to guarantee access for "all proper and lawful purposes," including mining, logging, and the building of irrigation ditches. It also specified the purposes of federal reserves: to provide a continuous supply of timber and secure favorable conditions of water flow (see page 2 of text). In addition, the Organic Act contained the "All waters clause" which stated:

> *"All waters on such reservations may be used for domestic, mining, milling or irrigation purposes*

under the laws of the State wherein such forest reservations are situated or under the laws of the United States and rules and regulations established thereunder" (Steen 1/12 at 16; Wengert 8/13 at 134).

McCarthy (3/20 at 38, 90, 94-5) said the Organic Act represented a compromise between western and eastern interests, with the West winning more points. The East won a continuation of the reserve concept, with the Secretary of the Interior making rules and regulations on the reserves. The West won because the forest reserves were to be opened for use, and they won because the purposes for which reserves could be created had been restricted to the protection of timber and water flows.

Both sets of witnesses agreed that documentation from the 1890's contained the recurring theme that forests were important to water flows and therefore forest management and water management were linked. Irrigation interests were supportive of the reserves, and supported the theory that watershed protection was important for slowing down runoff and extending water flows longer into the irrigation season. However, opposition witness McCarthy (3/20 at 38, 120-121) said he had found no evidence of restrictions on water use or access to water on forest reserves.

The two sides argued over the meaning of the "all waters clause." The opposition asserted that it clearly meant state law would govern the appropriation of waters on federal reservations. The U.S. witnesses claimed that the clause was subordinate to the primary purposes of forest reserves to protect the forest and its water conveyance capacity, and that reference to laws of the states or of the U.S. meant that Congress could decide to enact a federal law which would address the use of water.

SCIENTIFIC KNOWLEDGE AT THE TIME OF THE ORGANIC ACT

The Influence of Forests on Streamflow and Erosion

It was the U.S.'s position that scientific knowledge of watershed and channel processes was widespread in the late-1800's, and was transmitted to Congress. Both prior to and following the 1891 Act, Congressional records repeatedly contained statements about protection of trees and undergrowth from fire and axe, and the importance of forests for regulating flows and preventing erosion. It was recognized that if forest cover (i.e. leaves, trees, root systems, decaying matter, underbrush) was removed, snows would melt too fast, springs would dry up, droughts and destructive floods would increase, and erosion would accelerate. Regulation of flows by the forest cover was seen as beneficial for agriculture. However, little hard scientific data existed in the late 1800's to support these perceived relationships between forest cover, rainfall and stream flows. The first watershed study in the U.S. wouldn't start until 1909 at Wagon Wheel Gap, Colorado.

Wengert (8/13 at 78) said that conservationists supported these ideas based on observation and intuition. Engineers generally didn't support them, "but had no better argument than their exceptions to observations and a dislike of intuition." This difference of philosophy would become apparent in the WD1 case as well.

Channel Processes

The U.S. experts maintained that excessive erosion and sediment in streams was considered an "unfavorable condition" back in the late 1800's. They also said it was known at the time that reduced flow volumes caused sediment to deposit out. The opposition did not disagree that increased erosion from the destruction of forest cover was considered to be undesirable, but argued that there was no support at the time for the idea that diversions had negative effects on stream channels.

Bernard Fernow, who became chief of the Division of Forestry (predecessor of the Forest Service) in 1886, had substantial knowledge of channel processes and sediment transport, and transmitted this information to Congress through various reports. An 1889 report by Fernow contained a statement which indicated knowledge of fluvial geomorphology at the time:

"Since this detritus is deposited wherever the velocity of the water sinks below that necessary to carry it, forming sand banks and rubbish heaps which obstruct and change the direction of the run, it plays quite an important part in shaping the bed of the river, besides influencing the whole system of dependent brooks and rivers" (Wengert 8/13 at 87).

In an 1891 report, he made a statement specifically tying favorable conditions to sediment transport in streams:

"These surface waters also loosen rocks and soil, carrying these in their descent into the river courses and valleys, thus increasing dangers of

high floods and destroying favorable cultural conditions" (Steen 1/11 at 127).

The opposition asked why, if Congress was aware of these problems, they didn't consider diversions or reservoirs to be "abuse" of streams?

INTERPRETATION OF THE PHRASE "FAVORABLE CONDITIONS OF WATER FLOWS"

A primary objective of both sides in presenting historical evidence was to illustrate the intent of Congress by the words "favorable conditions of water flows." This phrase had remained consistent throughout documents developed prior to the 1897 Act, except that earlier versions used "flow" rather than "flows."

A key question posed by the opposition was, "favorable for what?" (Fischer 1/12 at 100-101). They said it was clear from the historical evidence that the ones to be benefited by favorable conditions of water flow were the water users—primarily irrigation farmers—although Congress had also mentioned towns and villages and mining activities.

According to U.S. experts, the intent of Congress in the 1891 and 1897 acts was to protect forests and the integrity of the stream channels for conveyance of water so they could contribute to a sustainable water supply for use in the valleys below. The opposition agreed that the main concern was to achieve favorable conditions of water flow through watershed protection, but believed this was limited to hillslopes. There was some discussion about the historical meaning of the term "watershed" and whether it included the stream channels or not; for example, a 1908 American Society of Civil Engineers paper contained the language "watershed and its streams" (Steen 1/16 at 19). However, in 1889, John Wesley Powell had referred to the hydrological basin as being a natural unit in which all problems were interrelated, and had actually called for governmental units to be defined by drainage basins.

Both sides expressed the opinion that one of the favorable conditions of water flow was the storage of water during flood flows (including spring snowmelt runoff) so flows could be extended longer into the summer. However, it was the U.S.'s position that regulation of flows was to be achieved through protection of watersheds and forests only. The opposition's opinion was that regulation could also be achieved by reservoirs and diversions. They claimed that the record showed no opposition to the use of surface waters, even to the point of totally dewatering streams. Wengert (8/9 at 47; 8/13 at 138) testified that he had never seen any concern expressed over channel maintenance during his review of historical documents.

Nash, a U.S. historian (1/9 at 216), used the analogy of diversions as being "like transfusions": a little donation was all right. Funk, attorney for the City and County of Denver, posed this question to Steen in regard to one of Denver's diversion structures: if securing favorable conditions of water flow (i.e. by maintaining watershed conditions) would benefit a water user outside the reserve, wouldn't it also secure the same benefit if the diversion were inside? Steen replied that he believed it would (1/12 at 116).

STATE AND NATIONAL POLICY FOLLOWING THE ORGANIC ACT

The U.S. supported the opinion that the intent of the Organic Act and related legislation was to preserve forests and watersheds, from which water would flow to the valleys below where it could be used for irrigation. The opposition claimed that there was no evidence that the Act intended to keep reservoirs, diversions and other irrigation structures out of forest reserves; in fact it allowed them under a permit system. They said there was no historical evidence of protests about the right to use or appropriate water on forest reserves.

Early Forest Service Policy

By 1898, controversy over the Organic Act had died down enough for Gifford Pinchot to write:

"The outburst of public protest which followed the establishment of thirteen reserves by President Cleveland has spent its force, and a widespread recognition of the value of the reserves to the communities about them is taking its place" (Wengert 8/13 at 144).

Roosevelt became president in 1901 after McKinley died, and was the main force behind reservation of forests in the early 20th century, adding about 100 million acres. He personally reserved much of the forest land in Water Division 1.

In 1907 or 1908, Congress reduced the authority of the President to claim forest reserves, but then reinstated it a few years later on a limited basis. In 1976, all of the forest reserves which had been proclaimed to date were made into law by Congress; since then, national forests have been a creation of Congress and can not be reversed or withdrawn by Presidential decision.

From 1897 until the Transfer Act of 1905 when forest reserves were turned over to the USDA, the General Land Office of the Department of the Interior was responsible for their management. The Organic Act was first administered through rules and regulations developed by the Secretary of the Interior and carried out by field officers. The 1902 Forest Reserve Manual and, after 1905, the Forest Service Use Books, contained guidelines on how officers were to implement regulations. These contained regulations on maintaining forest cover and on the permitting of ditches on forest lands. In the 1902 manual, permits were:

> *"only for the improvements necessary to store or conduct water and do not carry any right to the water itself, the appropriation of which is subject to Federal, State, or Territorial Law" (Wengert 8/14 at 65; Steen 1/12 at 58).*

Both the 1905 and 1907 Use Books were written by Gifford Pinchot, and the 1902 Manual contained writing with a similar style to his although it had a different author, Allen. Pinchot advocated "wise use" of national forests which would not conflict with the permanent value of resources, and in a 1907 public relations document, he wrote:

> *"the creation of a national forest has no effect whatever on laws which govern the appropriation of water. This is a matter governed entirely by State and Territorial laws" (Wengert 8/14 at 70-71).*

The inconsistency in wording about which water laws would govern created fertile ground for argument in the Water Division 1 case.

Federal vs. State Water Rights, and Policies on Irrigation Development

The Federal Government, in making a claim for federal reserved water rights, asserted that water rights were granted at the time forest reserves were created. The opposition argued that the historical evidence showed that water on federal reserves was subject to state water laws.

An important part of the opposition's testimony was the history of irrigation development, which they regarded as connected to the protection and reservation of forests. In 1897, the same year as the Organic Act, Congress had requested the Corps of Engineers (COE) to do a survey of reservoir sites. Language in the 1897 House document referred to the "ideal stream" as being one in which flow varied "directly with the magnitude of the uses to which it is put"; i.e. by using reservoir storage. Captain Chittenden of the COE had said that people were willing to "sacrifice the streams" to obtain maximum water for irrigation (Wengert 8/9 at 163).

The 1876 Colorado constitution contained this specific language on irrigation and water rights:

> *"Water of every natural stream not heretofore appropriated within the State of Colorado is hereby declared to be the property of the public and the same is dedicated to the use of the people of the state subject to appropriation as hereinafter provided."*

Wengert (8/9 at 100) said there was an expectation of some people at the time that the federal government might turn over public lands to states. Colorado's constitution also contained language which would have authorized management of those lands by the State.

Nash agreed that irrigation was entirely compatible with national forests, saying, "That is one of the reasons they exist." However, it was his position that people in the late 1800's thought flows should be regulated naturally in the uplands and if artificial regulation was needed, it should be done in the lowlands. He read from the 1907 Use Book by Pinchot which talked of the forests being "great sponges to give out steady flows of water for use in the fertile valleys below." It also said that canals, reservoirs, etc. could be constructed whenever needed "as long as they do not unnecessarily damage the forest reserve" (Nash 1/9 at 166; 1/10 at 85, 93-95, 116).

The opposition presented a large number of exhibits to support their position that the federal government allowed irrigation development within forest reserves, and actually advocated construction of reservoirs at higher elevations. They demonstrated that extensive irrigation works already existed in Colorado at the time of the Organic Act, and continued to be built afterwards - including diversions in the mountains.

The most substantial statement about building dams in forest reserves was given in a 1901 report of the Department of the Interior. It said that the first step in water conservation had been taken by Congress by setting aside wooded land, and that this should be followed by:

> *"the construction, within the forest reserves, and elsewhere when practicable, of substantial dams impounding flood and waste waters" (Wengert 8/14 at 8).*

President Roosevelt gave strong support to protection of the forests, which he said were "natural reservoirs." However, he also believed that forests alone were not enough to regulate and conserve water, and therefore "Great storage works are necessary to equalize the flow of streams and to save the flood waters." He believed federal involvement was necessary to develop the large irrigation works needed to serve whole communities (Wengert 8/14 at 41).

However, Roosevelt also apparently advocated minimum flow releases from reservoirs, saying:

> *"Where their purpose is to regulate the flow of streams, the water should be turned freely into the channels in the dry season to take the same course under the same laws as the natural flow" (Nash 1/9 at 176).*

Roosevelt was president when the Reclamation Act was passed in 1902. At that time, Colorado lead the states in the amount of arid land irrigated. The Reclamation Act provided for construction of irrigation projects, with ownership of the works and responsibility for their operation to remain with the Government unless changed by Congress. It contained the statement:

> *"That nothing in this Act shall be construed as affecting or intended to affect or to in any way interfere with the laws of any State or Territory relating to the control, appropriation, use, or distribution of water used in irrigation, or any vested right acquired thereunder..." (Wengert 8/14 at 29-30, 38).*

Although the Organic Act's "All water's clause" had referred to "laws of the United States," there appeared to be no federal laws governing water law on federal reserve lands except for securing favorable conditions of water flow. The judge in the WD1 case (1/12 at 39) entered a statement that a U.S. law would have to be passed in order to allow them control; otherwise water use was subject to State law with the Federal government's role limited to approval of right-of-way.

Forest Policy on Favorable Conditions of Water Flows

Policies were statements of ways in which the Forest Service implemented various laws and regulations assigned by Congress or the Secretary of Agriculture. They were an interpretation of legislative intent which was passed to field officers for implementation through the Forest Service Manuals and Handbooks. Policies evolved as a result of increased pressure on uses of natural resources, from feedback after field application, from court actions, from legislative direction, and as a result of developments in scientific knowledge.

Forest Service policy on securing favorable conditions of water flow under the Organic Act was to manage its lands and issue permits to avoid damage to stream courses or unnecessary erosion. Leonard, USFS Associate Chief, gave examples of Forest Service policy which included keeping heavy equipment and roads away from streams during logging operations, erosion control on disturbed areas, and restriction of grazing to maintain watershed cover.

The first Forest Service manual of 1905 had no regulations on channel maintenance or instream flows other than statements about maintaining the health of watersheds. The 1965 manual was the first time a Forest Service manual specifically mentioned the reservation doctrine. Before the 1978 "Mimbres decision," the Forest Service thought they had a right to all of the water on Forest Service land. In areas with no diversions, favorable conditions of water flow were maintained by relying on natural flows. The Forest Service did not generally pursue claims for instream flows before 1984, although it was involved in an instream flow case on the Big Horn River in Wyoming in 1979.

When the Water Division 1 claims were first filed in 1976, the 1974 Forest Service manual was in place. It stated:

> *"Water, including instream flows and standing water necessary for development and use of management of resources of the national forest system, will be obtained and used in accordance with the reservation principle where applicable."*

If the reservation principle wasn't applicable, the Forest Service was directed to obtain water rights through state laws or by purchase if they were essential to Forest activities (Reynolds 1/18 at 12-13).

In 1984, as a result of the Mimbres decision, the Forest Service issued a change to the manual to address channel maintenance for the first time.

Title 2500 of the Forest Service Manual set forth policies on watershed management. The manual stated that reserved water rights were public rights which the Forest Service was required to protect. To do so, Regional Foresters were directed to follow these procedures:

- Notify states of the Forest Service's instream flow rights by protesting applications for water rights which would adversely affect national forest reserves or water rights of the US.

- Assert claimed water rights under federal law as applicable.
- Claim water rights under state law where the state recognizes instream flow rights but requires that they be held in name of the state or a state agency.
- If water rights for instream flows cannot be established, other methods are to be used to insure protection, including special use permits, easements, agreements, memoranda of understanding, etc. (Reynolds 1/17 at 101-102).

In the Water Division 1 case, which was an adjudication of water rights, the U.S. came forward with its claims to notify others of the Forest Service's reserved rights.

Forest Service manuals gave policy direction. Forest Service handbooks described the actual procedures used to implement the policies. The procedure for claiming federal reserved water rights under the Organic Act was described in Chapter 30 of the Forest Service's Water Information Management System Handbook. Even though the Water Division 1 litigation actually came before adoption of **Chapter 30** in April 1989, that methodology was used for claiming instream flows.

Chapter 30 directed Forest Service officers to obtain water rights "with due consideration for needs of others." It also directed them to "use water needed for national purposes efficiently and in water scarce areas frugally." Following this policy of efficient use, the Forest Service directed its officers to claim the minimum flows necessary to maintain favorable conditions of water flow; i.e. to maintain the integrity of stream channels. In the Water Division 1 case, the Forest Service asserted that its claims were only for the minimum amount required (Reynolds 1/17 at 12-14, 98-99).

STATE OF COLORADO WATER POLICY

History

Colorado water rights, which are administered under the doctrine of prior appropriation, date back to the late 1850's and early 1860's. The first decrees were generally associated with mining and were direct flow rights (e.g. no storage). They were also basically non-consumptive because waters diverted for placer mining were returned to the stream. Major agricultural rights along the South Platte were established in the 1860's to 1880's, almost to the limit of dependable supplies. As water continued to be diverted and used for irrigation, some came back to the river as return flows. This increased groundwater recharge and had a delaying effect which extended the season over which flows could be diverted by downstream users. Many water rights in eastern Colorado and a compact with Nebraska have dates from the 1870's and 1880's.

After about 1880, direct flow rights were essentially fully appropriated. Reservoir development started at this time to store spring snowmelt runoff for later summer use by crops. Construction of reservoirs began at the best sites in the narrow canyons at the foothills of the eastern "front range" of the Rocky Mountains, where water could be supplied to valleys by gravity. Reservoirs continued to be built into the 1920's on the plains as well as in the mountains. Brand (9/14 at 22-26) said he had a "rule of thumb" that most of the reservoirs were built prior to the initiation of income tax," implying that more money was available then.

Because it was recognized that the water supply to the Front Range was limited, the Colorado-Big Thompson project (CBT) was built in the 1930's to collect water in reservoirs on the west slope of the Rocky Mountains and pump it through tunnels approximately 13 miles under Rocky Mountain National Park to the east slope near Estes Park and on through power facilities, lakes and tunnels to terminal reservoirs. Other transbasin diversions were constructed both before and after the CBT.

Since the 1920's and 1930's, administration of water rights has shifted in scope, with very few new water rights being adjudicated. Instead, existing rights are shuffled to provide water to the most users, in order of seniority. In the 1950's, the state experienced severe drought, and extensive development of the groundwater resource occurred. There was no law regulating its development at the time, but legislation was passed in 1965-1969 requiring wells to be administered within the priority system. Thus, diverting groundwater was the same as diverting surface water. But because these waters were already fully (or over-) appropriated, the legislature also provided for "augmentation plans" which allowed wells with junior rights to divert out of priority if they replaced the diverted amount by releasing water from reservoir storage so senior users would not be impaired.

At the time of the WD1 case, most of the effort of the Colorado State Engineer Office revolved around augmentation plans, exchanges, changes in place or purpose of use, etc., taking into account return flow components from upstream diversions. With some

40,000-50,000 water rights in the Platte Basin, the water rights system involved an exceedingly complex network of storages, diversions, upstream and downstream transfers of water rights, inter-basin transfers, credits for return flow, and augmentation of stream flows to replace ground water withdrawals - all operated in a manner to ensure that water supplies went to users in order of seniority. The Platte River was also operated under the Southwest River Compact, with obligations to Nebraska. This system was very over-appropriated and it was rare to have enough surface flows to satisfy all surface water rights.

The State of Colorado recognized instream flows as a beneficial use of water. However, it recognized fisheries as a valid basis for instream flow claims - not channel maintenance.

Administration of Water Division 1

The National Forests within Water Division 1 contained the headwaters of the Laramie and South Platte Rivers. In the mountains, the precipitation occurred mostly as snow; in the plains, mostly as rain. The Rocky Mountains created a rain shadow effect, with precipitation averaging 40-50 inches per year on the west side as compared to 12-13 inches per year on the east. Some 50% of the annual stream flow occurred in May and June as spring runoff, and streamflows typically tapered off in the summer. Both municipalities and agriculture had difficulty matching their demands to the natural runoff hydrograph.

Water Division 1 was divided into water districts which generally represented watersheds. A water commissioner in each district administered water rights on a daily basis according to the priority system. Each day, he or she evaluated available water supplies and demands. If supplies were insufficient to meet all demands, a senior water right holder could place a "call" on a stream, requiring the senior rights to be filled before demands of upstream junior users. Hoff, a water commissioner in Water Division 1 (6/26 at 113-123), described the day-to-day administration tasks which included receiving requests for water; setting ditches based on priority, water rights and the amount of streamflow; collecting and compiling streamflow and reservoir level data; checking return flows; and checking "zero discharge points" which were dry if the river was being run as efficiently as possible.

Junior rights in mountain reservoirs usually obtained water during "windows of opportunity" in May and June during peak runoff. Exchanges to upstream reservoirs generally took place at this time. This water was commonly stored up high, often out of priority, with the expectation that return flows from irrigation would allow filling of senior reservoirs downstream. For example, a city could purchase senior water in a downstream reservoir, and provide water to the senior user by exchanging junior water released from a higher reservoir. Another example was given by Hajj (7/30 at 55-9) of a pending application to exchange municipal effluent from the City of Thornton on the South Platte River for higher quality water in the Poudre River. Exchanges could therefore be exceedingly complex, involving wells, reservoirs, return flows, priorities which changed with the time of year, and interbasin transfers.

Potential for Injury to Other Water Rights

The U.S. had a continuing objection against evidence on injury, contending that it wasn't an issue in this case. They believed the court should decide whether the Forest Service was entitled to reserved water rights for channel maintenance flows, and if so, how much. However, the judge pointed out that the U.S. had already made injury an issue because they made allowances for existing water rights in developing their instream flow claims (3/19 at 7-18). For example, the claims were for maintaining the channels in their present form rather than in "pre-white man" natural conditions - even though the existing channel form might have been influenced by diversions.

To establish the instream flow claims, the Forest Service selected "quantification points" on a stream-by-stream basis. It was the Forest Service's position that the placement of these points took other water users into consideration; otherwise, claims could have been made from the National Forest boundary all the way to headwater regions, requiring much less effort. The Forest Service also arranged settlements with several water users who could have been affected by the U.S. claims. Further, the Forest Service recognized that its claims were for nonconsumptive rights which were not being used other than to maintain the natural delivery system; thus the water would be available for users downstream. The U.S. would later claim that about 2/3 of the quantification points would have no impact on other water users, either because there were no diversions upstream or because of settlements.

Demonstration of injury to water users was a major theme in the opposition's case. Although they generally agreed that the U.S.'s claims were non-consumptive except for minor evaporation losses, they argued that the claims could still have an effect on other water rights, including exchange agreements, the ability to divert or store water during the spring runoff season, and the ability to build new reservoirs at high elevations. The claims would also reduce the amount of return flows if water couldn't be diverted for irrigation of upstream lands.

According to Danielson, Colorado State Engineer (3/19 at 72-74, 101, 114-6), existing water rights were adapted to—and had in turn altered—the flow regime of the last 100 years. Anything which would alter this established regime would be detrimental to existing or new water rights. The U.S. claims would have the effect of placing previously unrecognized, relatively senior water rights, into the system. If the U.S.'s claims were approved, injury would most likely occur to junior rights upstream of the National Forests and senior rights downstream, as well as creating administration problems.

The opposition argued that the existing water rights system would allow more flexibility as competition for water resources increased in the future. Flexibility was also needed because some watersheds produced more water than others in comparison to demands. In fact, because some water was unusable due to groundwater contamination (e.g. from the Rocky Mountain Arsenal and City of Denver sewage flows), some areas could already experience shortages during drought.

McDonald, director of the Colorado Water Conservation Board (6/28 at 65-68), said that increasing demands for water in WD1 would probably be met by:

- developing the supply remaining under the South Platte River Compact by storing water during the spring runoff peak,
- purchasing water rights from willing agricultural owners and transferring them to the municipal sector, or
- developing new innovative exchanges and management techniques.

All could require additional or enlarged upstream storages, preferably upstream of metropolitan areas. Opposition witnesses gave these benefits of storing water at a high elevation:

- less evaporation because temperatures were lower and because mountain reservoirs tended to be deeper with less surface area than plains reservoirs,
- less sedimentation of reservoirs,
- greater hydropower potential,
- gravity delivery of water,
- increased opportunities for multiple use of the water because of return flows from upstream users,
- increased flexibility of management, e.g. for providing for out-of-priority diversions through upstream exchanges.

Both sides questioned the others' level of analysis regarding injury. Cargill, USFS Regional Forester (1/22 at 7, 43), said the U.S. had done a case-by-case analysis for objectors who wanted to discuss settlement, but not for other water users. U.S. witnesses agreed that their claims could have an effect on water rights such as reservoirs and ditches which didn't predate the forest; however, there were also many water rights which were older than the National Forests. The senior rights downstream of the Forests would "pull though" the water and would essentially have the same effect as an instream flow claim.

Another point brought out by the opposition was that the Forest Service claims were unlike most water rights which were either "on or off on their given amount" (Berryman, 6/26 at 30). Instead, the Forest Service claims required frequent adjustment of the hydrograph which would present problems with administration. The State witnesses believed that continual monitoring of flows at remote sites (e.g. by satellite systems) and additional staff would be needed, creating additional expense. The Forest Service claims also required quantifying the instream flow claims upstream of each quantification point by proportion. The State was unclear as to what this language meant or how to administer it. They did agree that the U.S. claims wouldn't need to be administered unless the Forest Service issued a "call" to shut someone else down.

WERE FEDERAL RESERVED WATER RIGHTS REALLY NEEDED?

The opposition challenged the Forest Service's need for water rights at all. They argued that the Forest Service had other means at its disposal to control dams and diversions which could be done on a site-by-site basis, and which would not have as much impact on the existing structure of water rights in Water Division 1. Other mechanisms included:

- Controlling activities on National Forest lands using special use permits, Environmental Impact Statements, and other meth-

ods for protecting streamflows including Wild and Scenic River designation and Section 404 of the Clean Water Act.
- Instream flow water rights with a 1990 priority date.
- Only asserting reserved rights when someone filed for a right which affected the forest.
- Utilizing Colorado's program of instream flows. There were several hundred instream flow rights in Water Division 1 decreed to the Colorado Water Conservation Board. State instream flow claims were for the amount needed to sustain a cold water trout fishery, and were generally less than U.S. claims. They were also for a specified reach, for steady rates of flow with set time limits, and had very junior priorities (1973 or later) so they did not affect other water rights in many cases.

U.S. policy witnesses believed that other management options were insufficient. The third option was not possible because this case was an adjudication case in which the Forest Service was required to come forward with its claims. A 1990 water right would not be adequate because of the large number of existing and outstanding water rights which would be senior to a 1990 claim. Angel, attorney for the State of Colorado (1/18 at 104), pointed out that the Forest Service had subordinated its claims to other water rights during settlements, implying inconsistency.

According to Reynolds, the Forest Service was authorized to use special permits, easements, rights of way and other means to maintain instream flows necessary "to fulfill all national forest uses and purposes" (1/18 at 31). One of the principal statutes used was the Federal Land Policy Management Act. In relation to water development projects, special use permits could require various types of mitigation efforts such as site rehabilitation, prevention of erosion, protection of vegetation or aquatic habitat, fishery or channel maintenance flows, etc. Individual situations were considered on a case-by-case basis (1/17 at 46; 1/18 at 31, 74-81).

The Forest Service's position on special use permits was that in the short term, they could achieve the same effects as reserved water rights for maintaining stream channels in Water Division 1 if a regimen of instream flow was required as a condition of the permit. However, it was not the preferred method because in the long term it would not have the benefit of an adjudicated claim. Special use permits could be changed when they came up for renewal, and were easily challenged in court. They were not a long-term management tool, and did not have the same status as a water right which was a property right. It was the Forest Service's responsibility to not give away government property or to take actions which diminished their value. Reserved water right claims obtained through the adjudication process would give other water users more certainty about how much water the Forest Service needed than the special use permit process would.

SUMMARY OF HISTORY AND POLICY ISSUES

The U.S.'s Viewpoint

It was the U.S.'s position that the intent of the Organic Act and related legislation was to preserve watersheds and their streams within the National Forests, from which water would flow down to water users. At the time, knowledge was widespread that unless watersheds were protected, erosion would increase, streams would flood more and dry out sooner, and channels would fill in with sediment, affecting channel stability and increasing the potential for flooding. "Favorable conditions of water flow" were those which maintained the channels to prevent these undesirable effects.

They further argued that federal reserved water rights existed when the National Forests in WD1 were reserved, and that federal policy since the time of the Organic Act had been consistent with its original intent. Other management options, e.g. special permits, were not sufficient to protect the instream flows necessary to meet the purposes of the National Forest. The claims themselves were non-consumptive and wouldn't reduce the total volume available to downstream users.

The Opposition's Viewpoint

The opposition asserted that the historical record had shown great support for development of irrigation projects—even in forest reserves—and a continued deference to state water laws. "Favorable conditions of water flow" were those which met the year-round needs of Colorado cities, irrigators and other water users by storing spring runoff in surface reservoirs or underground (e.g. as return flows) to create a more uniform hydrograph. A number of witnesses testified that they had not observed - or received complaints about - any of the adverse effects of diversions which the U.S. claimed would occur without channel maintenance flows. The opposers also claimed there was no historical record of such effects; in fact they believed sediment was regarded as beneficial because it could seal ditches, reduce seepage losses, and provide nutrients when spread over farmlands.

The U.S. claim, even if it was non-consumptive, could still prohibit other water users from exercising exchanges. Because under Colorado law, water rights were property rights, this interference could constitute injury to water users. This injury wasn't balanced by the need to remedy flooding problems relating to channel maintenance because these problems had not occurred in a 100-year history of diversions. Simpson, manager of the Northern Colorado Conservancy District (6/24 at 43), said that no company or municipality had ever asked for a release of water to clear sediment from diversion headgates, and that this use would probably not be considered a "beneficial use" or be approved by the Colorado Board. Water users had relied for many years on the use of the National Forest for collection and storage of water and attenuation of floods. The present claims departed from actions of the Forest Service over the past century, and threatened damage to present and future water users.

Section 3.
Theories on Channel Formation and Maintenance

FUNDAMENTAL PHILOSOPHIES

The U.S.'s Viewpoint

The concept of channel maintenance emanated from the science of **fluvial geomorphology**, which pertained to the shape of rivers and the physics of their formation. Figure 2 contains excerpts from U.S. exhibits on terms and principles used in fluvial geomorphology.

Luna Leopold, an internationally renowned fluvial geomorphologist, used the phrase, "rivers are the authors of their own geometry" (1/24 at 24). Over time, they would adjust their dimensions (width, depth, slope, pattern, etc.) to convey the intermediate flows within their banks – those which occurred a few times per year on the average. The very large flows occurred too infrequently and the very small flows carried too little sediment to shape the active channel.

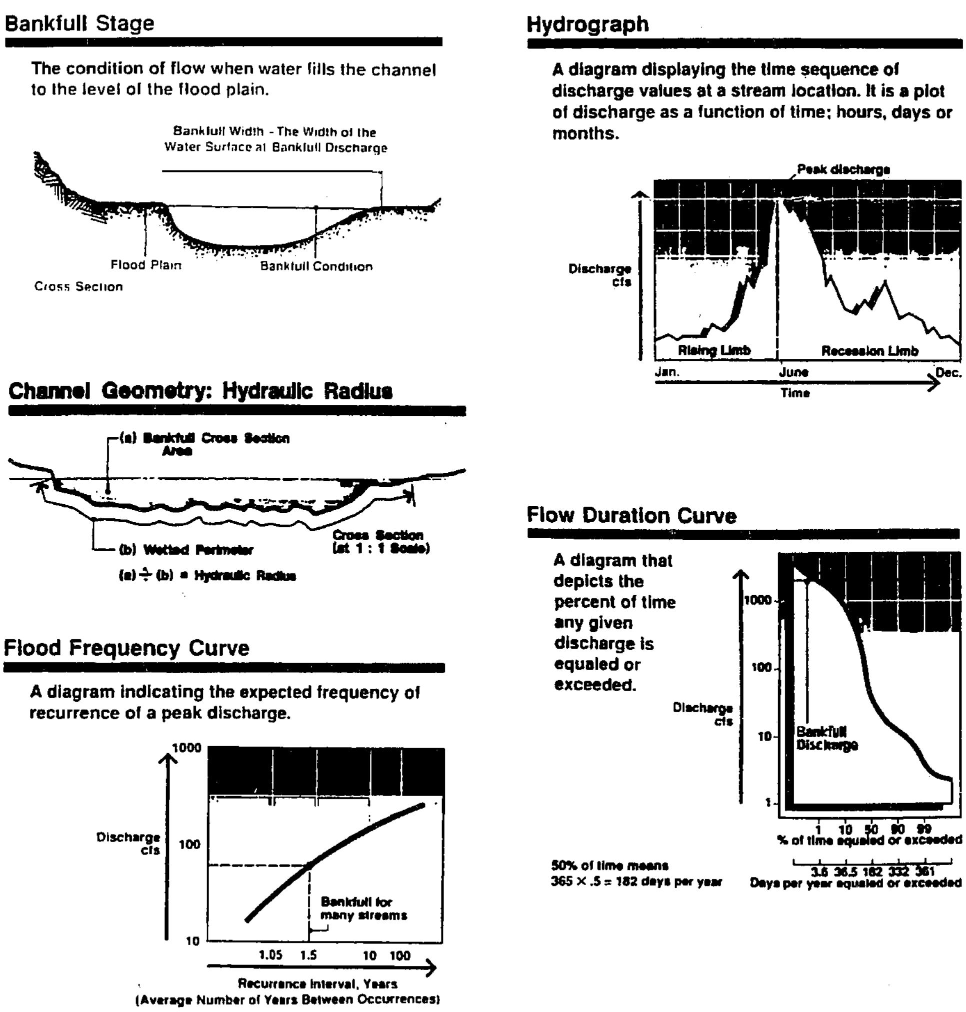
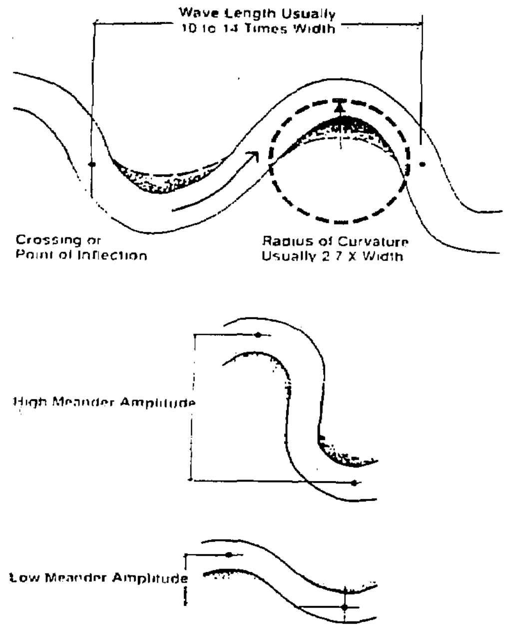


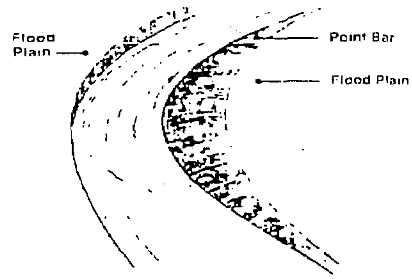
Figure 2.—Terms and principles in fluvial geomorphology as defined by the U.S. From Exhibit [A-327 and 508].

Meander Curve

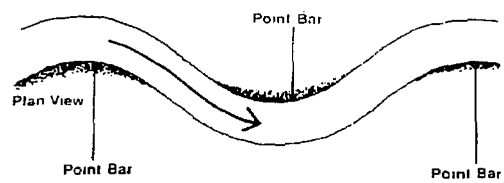


Point Bar

A deposit, often gravel, formed along the convex bank of a stream curve. The top of the point bar is usually at the level of the flood plain.

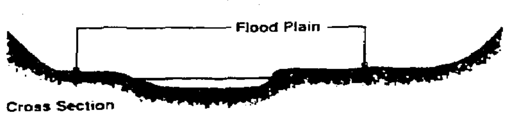


Point bars usually occur alternately on opposite sides of the stream.



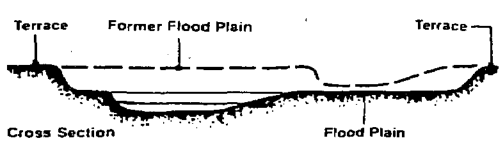
Flood Plain

Flat area adjacent to the channel constructed by the river in the present climate.



Terrace

An abandoned flood plain. It is the former flood plain constructed by the river in a former climate.



Alluvium

Sediment transported and deposited by flowing water. The flood plain is constructed of alluvial deposits.

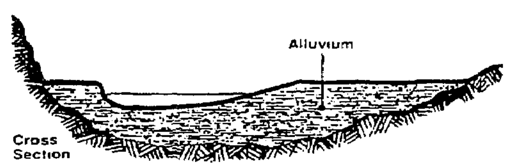


Figure 2 (continued).

The flow which just reached the level of the floodplain, the **bankfull flow**, was considered by Leopold to be the **channel forming discharge**. This was also closely coincident with the **effective discharge**, the flow which carried the most sediment over a long period of time (Leopold 1/24 at 31, 75-76, 82). Bankfull flow occurred about every few years on average. It was the U.S.'s position that if the frequency or size of near-bankfull flows were reduced by dams or diversions, the channels would become smaller in size as they adjusted to the new flow regime.

Leopold discussed the concept of "**quasi-equilibrium**," which was developed by G.K. Gilbert in the late-1800's. Over the long run, a stream in quasi-equilibrium would deliver the same amount of sediment downstream as was supplied to it from the upstream watershed (1/23 at 155). U.S. experts contended that sediment continuously entered stream channels from upland areas and tributaries, and if channel maintenance flows were not provided the sediment would accumulate and vegetation would encroach into the channel. This would lead to unfavorable conditions of water flows, including:

- Reduced channel capacity for carrying flood flows, which would exacerbate flood impacts
- Accelerated stream channel erosion, deposition, lateral migration and/or **avulsion** (the formation of an entirely new channel) when high flows passed through the smaller channel
- Increased deposition of sediment in reservoirs

The U.S. instream flow claims were designed to remove the majority of sediment supplied to the channels, with the objective of maintaining a stable, functioning, self-maintaining stream system (Rosgen 2/7 at 144-145; 2/9 at 71-72, 172-174). In Rosgen's words, it was important to maintain the "health and function of the system" because streams would take care of themselves more easily than humans could. He said the cumulative effects of disturbances to streams were like "getting nibbled to death by a duck;" i.e. relatively insignificant "bites" could add up to a major impact (2/9 at 146; 2/13 at 131-132).

Methods for constructing the U.S. claims were outlined in Chapter 30 of a Forest Service Handbook on Water Management. U.S. researchers had found that approximately 50% of the average annual flow of the WD1 streams could be diverted without appreciably affecting bankfull dimensions if:

- <u>bankfull flows</u> were provided for roughly their natural frequency and duration,
- <u>base flows</u> were provided in order to prevent vegetation encroachment during the growing season, and
- <u>rise/recession flows</u> on either side of the bankfull "peak" flow were claimed because channels were "developed by natural processes to accommodate rising discharges and falling discharges as well as a certain number of days of channel-full discharge" (Leopold, 1/24 at 6-7; Andrews 2/20 at 94, 137).

Further justification for claiming rise/recession flows was given in Chapter 30 (Section 32.8, Step 5), which stated that most sediment transport would occur during the early part of the hydrograph where flow increased from mean annual flow to bankfull. In Section 36.44, it also stated that the hydrograph should not be dropped suddenly from bankfull to base flow because a gradual recession was needed to prevent streambanks from collapsing due to pore pressure in saturated cohesive soils.

The claims were designed to move both finer and larger sediment materials in order to keep channels from becoming clogged. Even though the bulk of sediment transported by streams was finer material, the larger rocks were important in channel form. Particles of a given size would move at a variety of discharges, which was the reason for claiming a range of flows from base flow to bankfull (Leopold 1/25 at 146-148).

Andrews (2/20 at 132-134) said there were actually two issues:

1. Maintenance of channel size and conveyance
2. Keeping the channels in equilibrium (where sediment transport = sediment supply)

He said the 1989 Chapter 30 methodology addressed the first issue, but would not insure channel equilibrium because flows *higher than bankfull discharge* were not being claimed. The channel capacity of the active channel would be maintained as it had existed historically, but the amount of sediment transported would be less than what was supplied to the channels from the watershed - if the assumption in Chapter 30 was true that sediment supply would not change over time.

The Opposition's Viewpoint

The objectors supported the general principles of fluvial geomorphology relied upon by the U.S. witnesses. They also supported the concept that dams and diversions could cause changes to downstream channels because of changes in the flow regime. However, the opposition's key point of disagreement was that these principles had been developed from studies of plains-type alluvial streams and did not apply to the mountain streams in the National Forests within WD1. They maintained that the WD1 stream channels were not in equilibrium or "fully adjustable" because their dimensions were influenced by non-fluvial factors including large boulders, beaver dams, log jams and bedrock - and that they were formed by floods much larger than bankfull. The recession flows weren't needed because the streambanks were low and composed of non-cohesive materials which would not collapse due to pore pressure. The streams also didn't carry much sediment, and therefore only low flows, if any, were needed to transport this sediment downstream. Furthermore, they argued that if flows were reduced in these streams due to diversions, then the stream power and erosion of channel banks would also decrease, reducing the amount of sediment supplied to the channel (Schumm 3/21 at 76, 129; 3/22 at 35-43, 41-42; 3/26 at 8, 108-109; Simons 4/11 at 56-58; Li 6/7 at 55-58, 60-62, 65-67, 127-129; Mussetter 6/20 at 122-126).

Schumm (3/21 at 125) said it took "much more energy to form a channel than . . . to maintain it." It was the opposition's conclusion that the streambeds of the WD1 channels were composed of large materials which could not be moved by frequently occurring flows, and the smaller materials which were washed into the streams could be transported by relatively low flows. Therefore a reduction in flow would not have a major impact, and the range of flows claimed by the U.S. were not needed for channel maintenance.

Both Danielson and Berryman (3/19 at 97-100; 6/25 at 41; 6/26 at 36-37) said they were not aware of any unfavorable conditions in or below the National Forests in WD1. If there were any conditions of increased flooding or heavy silt loads below diversions, they would have heard about them. They pointed out that reservoirs attenuated peak flows, and that the State Engineer Office sometimes had people divert water even when they did not need it to spread out flows and lessen downstream damage. Therefore, diversions added to a system's capacity to carry flood waters.

INTERPRETATION OF BANKFULL LEVEL

The U.S.'s Viewpoint

Chapter 30 said bankfull flow could be approximated by the 1.5 year flow. For the WD1 streams, Leopold said this varied from 1 to 3.5 years and averaged about 1.5 years. He also pointed out that the 1.5 year value was based on an **annual flood series**, composed of the largest instantaneous floods from each year of record. A **partial duration series** contained the highest flows above some level, where some years might have several peaks and some none. Based on this series, bankfull frequency was about 2 times per year. Leopold said a few days of bankfull flow could be expected during the snowmelt season on average, but that it might not occur in a dry year (1/25 at 121-125).

In the field, the U.S. used a geomorphic definition of **bankfull level** which was equivalent to the level of the active floodplain under present climatic conditions (Leopold 1/24 at 40, 105; 1/25 at 37-38). Point bars were formed primarily during discharges near bankfull, and since the top of a point bar was level with the building floodplain, then it was one of the best indicators of bankfull level. Leopold (1/24 at 91-99) said the primary indicators used to identify bankfull level were:

- the level of the top surface of a point bar where it turned into the floodplain,
- a slight change in topography (e.g. gradual to steeper slope),
- a change in vegetation, particularly in mountain streams; e.g. change in density, change from lichens, liverworts or mosses to grass, or grasses to herbs/shrubs; and changes from dark to light coloration on rocks.

Leopold mentioned that not all indicators may be present, saying, "you may be left with only one indicator... and it often takes an experienced person to determine that" (1/24 at 99, 103).

Rosgen explained that the geomorphic bankfull stage was a "scour level" where the frequent bankfull flows worked on the streambank (2/8 at 87). For a wide plains-type stream, bankfull level could be the same as the top of the banks, but for confined channels, this would not be true. Rosgen showed a photograph of a channel where the bankfull level was only about 70% of the distance up to the banktop. The banktop represented an abandoned floodplain or **terrace**, and corresponded to a capacity 2-3 times greater than the U.S.-defined bankfull channel (2/8 at 89-90, 96-97). Rosgen said if the channel were being evaluated as a conduit with a certain capacity, the banktop level might be an appropriate "bankfull" measure. However, this level might only be reached during a 100-year flood or greater. When dealing with processes of adjustment to changing levels of sediment or discharge, the geomorphic bankfull level was more appropriate because it was related to conditions which shaped and maintained the channel. To fill the channel to the top wouldn't necessarily mean that the channel would maintain the same morphology (2/8 at 89-91).

As an example, Chavez discussed an arroyo where the active floodplain was well below the banktops. She explained that the stream had downcut as a result of watershed damage which was mainly caused by activities at the turn of the century. The whole channel would only be filled during a "major flood." Although the channel could contain these flood flows, they would cause lateral migration and erosion (2/5 at 152-155; 2/6 at 69-70).

The Opposition's Viewpoint

Walch, an attorney for the U.S., cited a paper by Williams of the USGS which gave an excellent synopsis of the differences in opinion between the U.S. and the opposers about bankfull level:

- "the fluvial geomorphologist. . . concerns himself with the active floodplain as the most meaningful bankfull level," and
- "the valley flat level represents the most significant bankfull discharge from the engineer's viewpoint" (4/5 at 106-108).

The opposers used the engineering definition of bankfull level as the level where the water would spill out over the top of the lowest bank and cause a flood. Simons clarified the opposer's definition by saying "you surely wouldn't take top of bank in the Grand Canyon" (4/11 at 97-99; 4/12 at 12-13). The opposers had used this definition because the Forest Service had tied its claim to an intent to decrease the potential for flooding. The Forest Service's definition was not related to channel capacity (Harvey 4/3 at 753-756). Schumm agreed that some people used the top of point bars and the lower limits of vegetation for indicating "the 1.5 year recurrence interval flow, which may or may not have anything to do with bankfull" (3/26 at 45). He said he had "trouble identifying what is defined by the Forest Service personnel as floodplains and banks" (3/21 at 39-40). According to Harvey, the way the Forest Service defined bankfull level was "singular to this case" and was based on Leopold's association with the Forest Service (4/3 at 750-751).

Harner, a vegetation expert for the opposition, said it appeared to him that the U.S. bankfull level represented a break in the vegetation between mosses lower down on the bank and herbaceous and woody species above (6/4 at 59-60, 64). Harvey, an engineer, believed the U.S.'s definition represented the contact between noncohesive sand and gravel materials near the streambed and the root-reinforced, finer material above. He also believed the U.S. had tied their definition of bankfull to an average recurrence interval of 1.5 years, and said the frequency with which flows reached the top of the bank would be much higher. Williams' paper had given values of 1-50 years (Harvey 4/2 at 559-562; 4/5 at 113-118, 121; 4/9 at 67).

Simons agreed that if a stream were fully alluvial and had a floodplain, the State's and the Forest Service's procedures for identifying bankfull level would be the same; however they differed in the mountain streams where floodplains were narrow or incised within terraces. The opposition called the Forest Service's bankfull level the "wash line" or the "ordinary high water mark" because it was reached every year on average (Simons 4/11 at 97-99; Li 6/7 at 62-63; Harvey 4/4 at 825-827; 4/5 at 84-85; Richardson 7/25 at 89-90).

The opposition maintained that Chapter 30 defined bankfull level as being at the tops of banks (Simons 4/11 at 97-99; Harvey 4/5 at 148-149). Section 36.3 of Chapter 30 contained this description of bankfull level which could easily be interpreted either way:

> *"The top of the bank is defined as that spot where the floodplain and channel meet, and it is distinguished by a break in slope. If a person were climbing out of a stream channel, he would generally have to dig in his toes to get up the bank, but could begin walking flat-footed when he reached the break in slope at the top of the bank."*

Harvey gave a number of criticisms of the Forest Service's method of identifying bankfull:

- <u>The tops of bars were not a good indication of bankfull.</u>

  Harvey said point bars were not flat - they were steep features with lower, middle and upper surfaces. He believed the U.S. was using the middle surface, which was covered by water on an annual basis. He also argued that the elevation of bars would change along a channel and over time as the radius of curvature of the bends in the channel changed. Harvey said the Forest Service had assumed that every bar was a point bar, but some could be alternate bars which migrated and some could be localized deposits controlled by bedrock outcrops (4/5 at 97-102, 105; 4/8 at 751-752).
- <u>Vegetation was not a good primary indicator of bankfull</u> because there was no agreement on what kinds of vegetation changes should mark the boundary. Vegetation grew irregularly along channel banks, and was affected by soil and water supply conditions (4/4 at 824).
- <u>The Forest Service's definition of bankfull described an intermittent, noncontinuous floodplain and it didn't "jive" with the idea of floodplains building by vertical accretion</u>

  Harvey said that the lack of fine-grained sediments on top of bars indicated that this was not the location of the floodplain. Floodplain sediments typically had an **alta fining sequence**; i.e. coarser materials below which graded to finer materials above (Harvey 4/2 at 559-561; 4/3 at 753-754).

- The Forest Service couldn't consistently identify its own definition of bankfull level.

During Harvey's testimony, the judge asked if it wouldn't be counterproductive for the State to argue that the U.S. should use a higher bankfull level, because it would increase their claim. Some people in the court nodded. He deferred this issue until final arguments at the end of the case (4/3 at 753; 4/5 at 84-90, 102-103).

DEFINITION OF THE TERM "FLOOD"

The U.S.'s Viewpoint

One of the U.S.'s assertions was that without channel maintenance flows, the channel would fill in, and this would exacerbate flooding effects because less of the flood water would be contained within the channel (Andrews 2/20 at 79). Leopold defined a **flood** as a condition in which the discharge was larger than what the channel could contain. However, he said "the land adjacent to the channel . . . is part of the channel, and the river needs it." He separated the term "flood" from the effects of floods, saying that floods caused damage because people had moved into that part of the streambed needed by the river to carry higher discharges (1/24 at 32, 39-40, 105; 1/25 at 37-38).

Andrews gave extensive testimony on channel encroachment and the fact that it was a well-recognized cause of higher flood water. He referred to FEMA reports for communities along the Front Range (east side of the Rocky Mountains) which mentioned how natural and manmade obstructions such as rock, brush, bridges, and buildings, could impede flows and raise flood heights. Woody vegetation growing within a channel could increase roughness by 2 to 3 times, decreasing the stream's velocity and increasing its depth and width. Vegetation could also accumulate floating debris, which became "one of the most damaging aspects of floods" when it was eventually carried downstream. The potential for flooding damage was high for roads which shared narrow canyons with the streams, and for houses and agricultural areas located at the mouths of confined reaches. Flood damages would be made "incrementally worse" by obstructions; i.e. a small amount of encroachment could cause a modest amount of additional damage, whereas if it were extensive, the damage would be substantial. The effect of dewatering a channel would therefore extend downstream of a diversion to the extent that the diverted flows made up a portion of the natural flow (Andrews 2/15 at 28, 50-59, 77, 86-98; 2/20 at 63-64).

Andrews testified that flooding was a natural process and had occurred frequently in the mountains of Colorado. From a flood frequency analysis of data from gaging stations in and near WD1, he demonstrated that floods of 2 to 10 times bankfull flow had occurred frequently. Bankfull discharge had an average recurrence interval of between 1.1 and 1.5 years. For these same streams, the 100-year flood was roughly 2.5 times the **mean annual flood**, which had a recurrence interval of about 2.3 years. He gave an example from the South St. Vrain Creek at Lyons, where bankfull flow was estimated as 800 cfs, but the largest flood of record was over 10,000 cfs (Andrews 2/15 at 63-65).

Andrews pointed out that the increased potential for flooding due to channel encroachment resulting from diversions had been recognized for a long time, and read this statement from a 1948 USGS publication, Floods in Colorado:

> *"The many diversions for irrigation have reduced the river flow to a mere trickle. This reduction in flow has resulted in a gradual choking of the channels by sediment and vegetation until eventually their capacity has become so small that when floods occur, the overflow for a given discharge is greater than formerly" (2/15 at 84-86).*

The Opposition's Viewpoint

The U.S. witnesses had tied their definition of "flood" to the geomorphic definition of bankfull stage. According to their definition, water flowing over bankfull level onto the active floodplain was a **flood.** However, the opposers tied the definition of flood to their definition of bankfull at banktop; therefore water flowing over the physical tops of the streambanks was a flood (Schumm 3/21 at 148; 3/22 at 11-12). Danielson, the Colorado State Engineer (3/19 at 95), defined floods as "flows which cause property damage or loss of life," or flows outside a well-defined channel. In confined channels, channel capacity could be much higher than the U.S.'s bankfull flow. Therefore a "flood" according to the U.S. definition wouldn't necessarily flow over the streambanks and cause flood damage.

The opposition argued that floods and flood damage would still occur with or without the U.S.'s instream flows (Fisher 2/20 at 140-141). They also argued that floods could sometimes have beneficial effects. For example, older "meadow" water rights relied on periodic inundation of lands during high flows. Another benefit was that if floodwaters entered alluvium on the floodplains, this water would be available later in the season either to wells or as **return flow** which slowly seeped back to the stream (Danielson 3/19 at 95-96; Berryman 6/26 at 39-40). Therefore, even if a lack of channel maintenance flows caused some loss of channel capacity, the additional water flowing outside the channel wouldn't necessarily be "unfavorable." In fact, spreading out the floodwaters within national forest lands could actually attenuate flood peaks downstream (Danielson 3/19 at 100; Berryman 6/25 at 48-49; Trout 2/1 at 101-102).

ADJUSTABILITY OF STREAM CHANNELS

The U.S.'s Viewpoint

Basic Processes

One of the basic principles of fluvial geomorphology was that channel characteristics were adjusted over a period of time so the amount of sediment supplied to the channel was transported by the range of flows passing through it. The size and shape of a channel was therefore intimately related to the amount of water and sediment delivered to it from the upstream basin. Andrews said this was true of all rivers which transported an appreciable fraction of the sizes of sediments found in the channel perimeter. It was a balance that a channel was always adjusting towards - although it might not exist at particular locations or times, e.g. at bedrock outcrops (Andrews 2/14 at 57-59; Silvey 2/1 at 40, 94; 2/5 at 87). Leopold said this principle was applicable to river channels world-wide, in both plains and mountain situations (1/24 at 24-25).

Channel characteristics included:

- Width
- Depth
- Velocity
- Slope
- Roughness of bed and bank material
- Discharge or volume of water
- Sediment load
- Sediment size

If any one of these variables was changed, the stream would begin to accommodate that change (Rosgen 2/8 at 10-11). Even though channel adjustment could be constrained by terraces or bedrock, the river would still "attempt to adjust those parameters that are adjustable under the circumstances." Channel width was one of the most adjustable parameters. Vertical adjustment occurred more slowly, but could be more sensitive to imposed changes (Leopold, 1/24 at 86-88). Channel pattern was another expression of change; e.g. in braided channels, the sum of the capacities of the multiple channels could be different than a single channel containing the same volume of water (Rosgen 2/9 at 172-174; Andrews 2/20 at 115).

Adjustable stream channels developed over time in a relatively predictable manner. Rivers had a tendency to meander, which was expressed in both horizontal and vertical profiles. Leopold found that the plan form of rivers tended to follow a curve of "minimum work" described by a sine-generated curve (very close in shape to alternating half-circles). The radius of curvature of these meanders tended towards 2.7 times the bankfull channel width. Trees, large rocks and other obstructions could cause streams to vary from perfect meanders. The meandering form was also associated with an alternation of deeps and shallows called **pools and riffles.** Pools formed against the outside of meander bends and riffles in between. These patterns occurred at relatively regular intervals of 5 to 7 times the channel width (Leopold 1/23 at 157; 1/24 at 46-47, 52, 90).

Rivers also had a natural tendency to migrate laterally. **Helical flow** was created at bends because higher velocity water near the stream's surface tended to be thrown against the outside bank, and slower water near the bed moved to the inner bank in compensation (Leopold 1/24 at 43-44). Sediment was eroded from the outside banks and deposited on the inner banks as **point bars.** The growth of bars increased the stress on adjacent outer banks, causing further erosion there. As the point bars developed, they became stabilized with vegetation and left a flat surface behind called the **floodplain.** The continual growth of point bars and erosion of the outer bank caused the channel to shift laterally across the valley, while maintaining the same width (Leopold 1/24 at 44-46, 49, 52-54; Rosgen 2/9 at 93-94, 132-133).

Leopold maintained that point bar building occurred primarily at relatively high discharges near bankfull stage. On many streams, lateral motion of the river took place generally after the peak flow because the high flows infiltrated into stream banks and then as water seeped back out, the bank was more easily eroded (Leopold 1/25 at 106-107). Erosion was therefore a natural geologic process. Simons, an opposition witness, agreed and said as an engineer he needed to evaluate whether an eroding bank was a stability problem or not by considering how fast it was eroding in relation to its position in the stream; i.e. more erosion would occur at a sharp bend (4/11 at 52-54).

It was the U.S.'s position that the streams in the national forests in WD1 were adjustable, and if flows affecting their character were altered, they would adjust their shapes in response to these changes. Rosgen said it was like a "series of dominoes" because increased bank erosion would lead to increased deposition of sediment and growth of bars, which would in turn affect the stream's velocity distribution and accelerate bank erosion (2/9 at 144-145, 162).

Rosgen said a stream which received imported water from another basin was an example of "too much water for too little channel," and was equivalent to the situation which would occur if high flows were returned to a silted-in channel below a diversion. He gave an example from Poudre Pass Creek which received imported flows via the Grand River Ditch[1]. It was incised and had low base flow and high bank erosion. Sediment yields were on the order of 1350 tons per square mile, which vastly exceeded natural yields. The example illustrated the fact that when more water was introduced into a channel than it was designed to carry, the channel would change its boundaries to accommodate the flow (Rosgen 2/9 at 160-172). Chavez made the comment that she could "safely say that every channel below a transmountain diversion has been eroded and is continuing to erode" (2/5 at 141; 2/6 at 67).

Wilcox also discussed the effects of augmented streamflows, using the example of streams which had been "tie driven." This referred to the practice of harvesting trees for railroad ties when the continental railroad was built in the 1860's. Trees were felled, cut into ties, then floated downstream. In streams with insufficient flow, the ties were sometimes impounded behind little dams. These were then breached during high spring flows, with "the whole mess of water and logs essentially ripping down the channel." Channel impacts were severe, and were still evident in some streams even 130 years later (Wilcox 2/7 at 15, 78-80).

The Fallacy of "Flushing Flows"

According to Leopold, the morphology of the stream - its point bars, meanders, pools and riffles - was controlled more by the larger materials than the finer sediment, even though the finer materials made up the bulk of sediment transported. If flows were not provided to move the larger materials, the channel would become clogged with "plugs or bars" and "groups of rock" rather than by an accumulation of alluvial materials. Leopold said that the bars could not be washed out by **flushing flows**, adding, "that is a great misapprehension in some circles . . . You can not flush sediment out of a channel in any uniform way. It has never been shown practical in practice" (1/24 at 133-136).

Both Leopold and Rosgen believed flushing flows would not only fail to clean out accumulated sediments but they would actually increase bank erosion and therefore increase the amount of sediment in the channel. Or, the flows could leave the channel and form an entirely new one (an "avulsion") (Leopold 1/24 at 136; 1/25 at 30; Rosgen 2/9 at 147-150). Rosgen elaborated on this by saying that flushing flows might work if the channel were steep, stable and confined (e.g. in bedrock), so all the energy was concentrated on the sediment. But in most rivers, particularly if the accumulated sediment were deposited in a point bar, the stream's velocity and energy would be lower over the point bars and more concentrated against the opposite banks. Therefore, instead of removing the sediment in the bars, the "flushing flows" would cause downcutting, undercutting and bank erosion. The eroded sediments would then deposit downstream and actually cause point bars to grow bigger, continuing the process (Rosgen 2/9 at 147-150).

If a stream pattern had been altered from meandering to braided, flushing flows would only cause further widening of the braided channel rather than restoring it. Rosgen said, "when you get a braided pattern started . . . no matter how many high flows that you have, it just seems to make it worse" (Rosgen 2/9 at 157-159).

Wilcox gave another example of the effects of "flushing flows" which had been used on Green Timber Creek in Colorado. A road crossing with a culvert had been built across the creek in connection with a timber sale. It had a cobble/boulder bed and a steep slope of about 4% at this location. During road construction, a thunderstorm occurred and carried massive amounts of sediment from disturbed areas into the creek and through the culvert. The cobble/boulder bed was buried by finer materials. Because this stream was one of the last places where Colorado River cutthroat trout could be found, management agencies were concerned about removing the sediment. They proposed to divert "flushing flows" into the stream from an upstream transbasin diversion in order to clean it

[1] *Richardson said the Colorado River was once called the Grand River. The Grand River ditch diverted water from the Colorado River Basin and had an 1890 priority date (7/25 at 37-39; 7/26 at 6-16).*

out. This was done approximately 3 times over one year for 2 to 6 days each time. Observers could hear boulders moving down the culvert during the flows. However, the flows were unsuccessful at removing the fine sediments which had filled in a downstream pool (2/7 at 39-49, 81-83). The judge summarized Wilcox's testimony by saying, "if you have a mess already in there, you can't get rid of it." Wilcox agreed with this (2/7 at 117-118).

Hydraulic Geometry

Leopold said the **hydraulic geometry** of a stream; i.e. the relationship of channel parameters (width, depth, slope, etc.) to discharge, was one indication of adjustability (1/24 at 86-87). He presented bankfull width vs. discharge relationships for the quantification points in WD1, for USGS gaging stations in the area, and for streams in other parts of the U.S. "where there could hardly be a question about whether they are adjustable." The plots showed scatter, which Leopold said was typical of hydrologic data; however, trends were very similar. For many stream systems world-wide, channel width tended to increase downstream in proportion to the square root of discharge. A line fit to the Arapahoe/Roosevelt National Forest data (fig. 3) had exactly this slope (Leopold 1/24 at 50, 120). R^2 for the relationship was 75% (Schumm 3/21 at 136-146).

Adjustability was related to sediment transport; therefore if channel width was being maintained, it indicated the channel was able to deliver out of the system the same amount of sediment coming in. Leopold concluded that even in the steeper, rockier mountain streams of Water Division 1, channel widths were related to discharge, indicating that these streams were adjustable (1/24 at 89, 109, 113-118).

In the Court's final decision, the judge commented on Leopold's statement that the *square root* of discharge was related to channel width and thus channel maintenance. The judge said he was therefore "bold enough to conclude—at least in a footnote—that even substantial changes in flow are likely to produce much smaller changes in the channel."

The Opposition's Viewpoint

Adjustability of the WD1 Streams

The U.S. attorneys spent a considerable amount of effort cross-examining opposition witnesses about the definitions of "alluvial" and "adjustable"

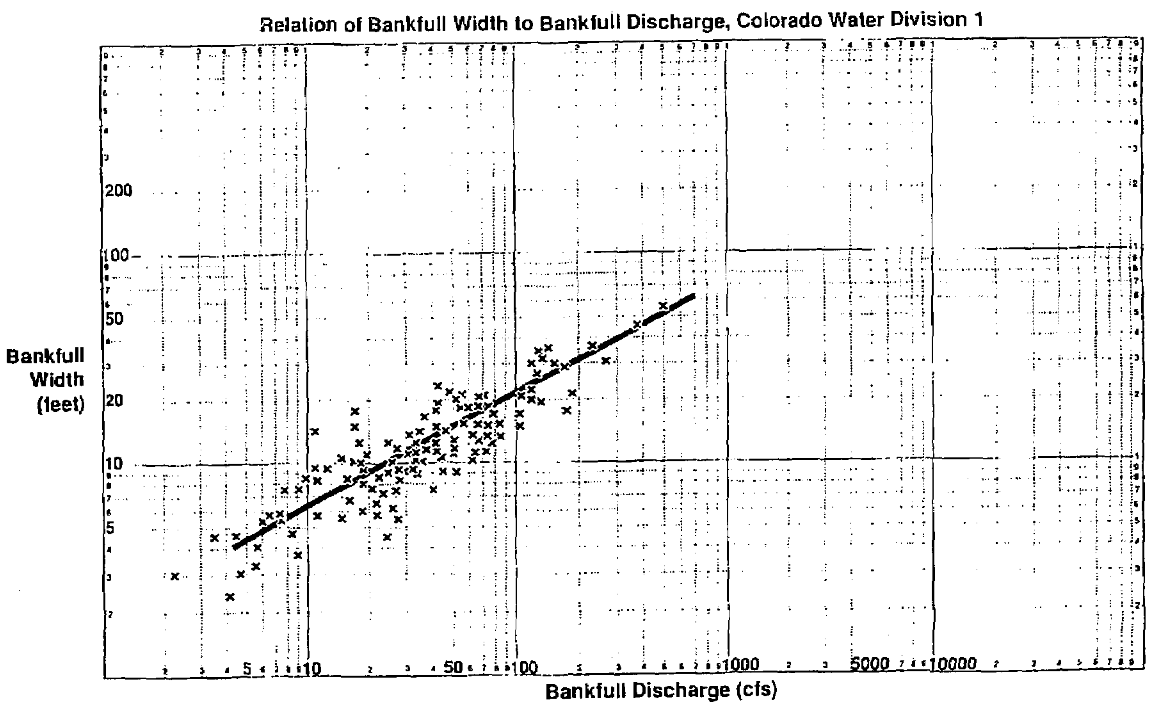


Figure 3.—Relationship of bankfull width to bankfull discharge for quantification points in the Arapahoe-Roosevelt N.F. (no ephemeral channels). From Exhibit [A-334].

and whether they meant the same thing. Schumm said that the Forest Service defined an **alluvial channel** as one with **alluvium** in its bed and banks, where alluvium was sediment transported by the stream. He was willing to accept that definition. He also said an alluvial channel was one in which the bed, bank and pattern could adjust with time, but not necessarily all at once (Schumm 3/26 at 9, 13, 56-57, 76).

The difference in opinion between the U.S. and opposition witnesses on adjustability boiled down to a question of whether the streams in the National Forests within WD1 would adjust to bankfull flows: the U.S. witnesses said they would and the opposition witnesses said they wouldn't, except perhaps in localized areas. The term "adjustable" was therefore relative and was not the same as "alluvial." Schumm (3/26 at 66) described the Mississippi River as a stream which had historically shifted across the floodplain over time like typical alluvial rivers; however it was becoming much more stable as the Corps of Engineers rip rapped banks and placed dikes in the channel.

Harvey described the following features and processes affecting "the performance, dynamics and form" of the WD1 channels to explain why they had stable forms (4/2 at 614-628):

- **glacial material:** Materials deposited by glaciers and/or reworked by glacial meltwaters were composed of a wide range of grain sizes. The smaller materials were "winnowed away" when the deposits were reworked by large streamflows, leaving the coarsest grains as a **lag deposit** which could not be moved by normal flows (Harvey 4/2 at 553-556, 4/9 at 44).
- **gravity-driven mass-wasting processes:**
  - **landslides:** These impacted stream channels by creating dams or by leaving lag deposits. Harvey mentioned a landslide which had dammed the Poudre River historically, but then failed and caused large boulders to be transported downstream (4/2 at 522-569).
  - **rockfalls:** These were common in narrow canyons and introduced large angular blocky material to the streams (4/2 at 579-584).
  - **debris flows:** These were a "slurry-like mixture of a wide range of grain sizes" which flowed like concrete under the influence of gravity (Harvey 4/2/90 at 583; 4/9/90 at 51). Harvey had observed these deposits in WD1, generally at lower elevations where small tributaries entered higher-order channels and formed fans (4/2 at 579-584).
- **megafloods:** These were very large events, rare under today's hydrologic regime, which could transport very coarse materials. Harvey said in glaciated areas, the glacial deposits were incised by megafloods caused when the glaciers retreated and released large amounts of water. Harvey said the literature supported the idea that "freak outburst floods" occurred when water accumulated behind ice dams, then burst through to cause large flood surges. He showed photos of "boulder berms" which were imbricated, indicating flood transport (4/2 at 535-537, 587-590; 4/9 at 61-66, 125-127, 135-139).

  The Big Thompson flood of 1976 was a more recent example of a megaflood. USGS researchers Costa, Jarrett and Pitlick determined that an event of this magnitude hadn't occurred in 10,000 years, but that even larger events had occurred in the past. The same researchers concluded that every stream along the Front Range below 7500 feet had experienced some type of catastrophic flood in the past 10,000 years, but these extreme events didn't occur above 7500 feet (4/2 at 587; 4/9 at 141-143, 148-149).
- **bedrock outcrops:** Harvey said these were "ubiquitous" in WD1 and prevented lateral adjustment of channels. He read from a presentation given by Dr. Tom Lisle, a USFS researcher who had said:

  > *"scour and deposition around bedrock bends and large obstructions in or along channels can cause bars to form where they would not form otherwise or at least fix the positions of bars and pools."*

  Lisle's work had also suggested that bedrock or other isolated hard points would affect upstream and downstream reaches for a distance of 2-4 times the channel width, due to effects on local hydraulics. Therefore, the presence of bars didn't necessarily indicate a meandering stream (Harvey 4/2 at 595-597; 4/9 at 105-106).
- **large woody organic debris (LWOD):** Log jams and debris dams were very common in the mountain streams. A LWOD could form a local **base-level control**, causing sediment to accumulate in the backwater area upstream and creating a "step". It could also

cause water table levels to rise, which could kill trees upstream - which would then fall in and continue the process. Channels tended to be wider upstream of LWODs. Downstream, materials were coarser and the channel narrower.

LWODs could cause changes in flow direction and avulsions. When log jams eventually rotted out, trapped sediments were flushed down through the system. Sediment transport became an "episodic" storage-release process (Harvey 4/2 at 597-601, 634; 4/3 at 683-687; 4/4 at 894).

- <u>beaver dams:</u> Beaver dams could create a "stepped" longitudinal profile, and the channel's position became a function of where the flow exited from the dams (4/4 at 893-898). Harvey had seen beavers on many of the channels that he visited. He cited a paper written in 1956 by the Colorado Division of Wildlife which estimated that 69% of the stream miles surveyed in Colorado had evidence of past or present occupation by beavers. He also cited a study done by the USGS in which evidence of beaver dams was found buried deep within valley deposits in Washington State, and was Carbon-14 dated at 5000 years old (4/2/90 at 603-611, 632-635).

Harvey said LWOD's and beaver dams were significant features over "engineering time," which he described as being about a 100-year period (4/2/90 at 634; 4/3/90 at 683-687; 4/5 at 60). He believed features such as boulder-step topography, megaflood deposits and glacial outwash were all alluvial features, but they resulted from flows much greater than those claimed by the U.S. (4/11 at 20). "Course of convenience" and "relic channel" were terms used by Harvey to describe a channel with bouldery materials which were not movable by frequently occurring flows. In these channels, there was no relationship between the dimensions of the channel perimeter and the frequently occurring flows claimed by the U.S. because the streams were shaped by some past event (4/9 at 5). Even in the 25% of the WD1 streams classified by Rosgen as "C-type" streams (wider, lower elevation streams; see Table 2), non-alluvial materials could occur, and these structural elements would affect the stream's adjustability (Harvey 4/4 at 924). Harvey also referred to another statement by Lisle, who had said (4/2 at 530-531):

"the widespread control of steepland channels by non-alluvial boundaries has received little attention and adds further complexity by invalidating the assumption of self-formation."

Harvey showed a number of photos of large boulders in streams which had come from moraines and were transported to their present location by glacial meltwaters. Lichens grew on the boulders, providing evidence that the boulders were not moving under frequently occurring flows (Harvey 4/2 at 539-546; 4/5 at 9-10). Schumm (3/22 at 45-46) showed similar examples of large boulders derived from rockfalls from canyon walls which were also covered by lichens.

In describing the plan form of the WD1 streams, Harvey (4/4 at 849) said the mountain streams had **"bends"** which were not the same as "meanders" in the plains streams because they were not created by the same processes. Schumm agreed that point bars weren't necessarily evidence of bank erosion or channel adjustment because he had seen point bars in extremely stable streams with very little amounts of sediment movement. The point bars in those streams could remain in one position for a very long time. In fact, in reviewing photographs of the WD1 quantification points, he only observed 5 locations with some bank erosion and only 1 where there was clearly a point bar (Schumm 3/26 at 22-23).

According to Schumm, the majority of the WD1 streams were not totally adjustable because of the presence of other factors which controlled channel dimensions. He said that a stream in **quasi-equilibrium** or **grade** "should be able to adjust its slope and width and depth and roughness," and if it could not adjust all of those components, Schumm did not consider it to be an adjustable stream (3/21 at 76). He said the entire channel certainly would not "adjust the way that we would expect to see in the Great Plains streams" (3/21 at 102).

Geomorphic Threshold

Leaf defined **geomorphic threshold** as a condition which, if exceeded, could cause acceleration of natural processes such as increased rates of bank cutting or increased deposition. Within the threshold limits, a stream could accommodate changes in flow regime or sediment yields without experiencing major alternations - i.e. it had a certain "resiliency" (8/1 at 33-34). In Leaf's opinion, it was highly important to evaluate streams on a site-specific basis to determine whether changes in flow regime would exceed that stream's geomorphic threshold (8/1 at 36-37; 8/2 at 91-93).

Schumm used the terms "sensitive" and "insensitive." He explained that sensitive land forms were those which responded promptly and dramatically to a slight external influence, whereas insensitive forms would not (3/21 at 26). In their work, both Schumm and Leopold had identified threshold conditions between braided and meandering streams. A stream close to the threshold would be "sensitive" because it had the potential to change abruptly, whereas a stream which was further from the threshold condition would be more insensitive or stable (3/21 at 80-81).

The opposition brought out that various procedures used by the Forest Service, including the models HYSED, WRENSS and a channel stability rating procedure by Pfankuch, all recognized the concept of geomorphic threshold. However, the U.S. had not addressed this issue in forming their claims (Leaf 6/28 at 129-131; 8/1 at 35, 60-68).

Leaf gave an example from the Fraser Experimental watershed, where long-term studies had shown that timber harvesting could increase water yields. In one watershed, Fool Creek, timber had been cut in a checkerboard pattern, leaving buffer strips of vegetation along streams. Water yields increased by about 25% after treatment, mostly due to an increase in flows on the rising limb of the hydrograph. This increased runoff along with rilling from road construction and disturbance of the mineral soils increased sediment yields in the streams. After the roads were closed and reseeded, sediment yields eventually returned to pre-treatment levels. However, water yields remained "persistently high" even 30 years after cutting. Leaf said the "moral" to be drawn from this example was that good logging practices were employed, and although sediment yields increased, they did not increase to the point that the geomorphic threshold was exceeded for the stream. This indicated flexibility in the subalpine watershed systems (8/1 at 37-43, 48-55, 63).

Leaf had also had some experience with watersheds where the geomorphic threshold *had* been exceeded, and gave an example from a stream in northern New Mexico. Its watershed had been extensively logged, and the stream was badly damaged as a result of improper logging practices and road drainage which had increased sediment loads. Leaf concluded that the geomorphic threshold had been exceeded in this stream. He said the northern New Mexico streams were more fragile than the Fraser streams, meaning a smaller increase in sediment load could cause the streams to exceed their geomorphic threshold (8/1 at 60-64, 66-68).

Leaf concluded by saying the subalpine channel systems in WD1 had a certain resiliency to accommodate changes in both flow and sediment. The threshold would be less wide in lower elevation watersheds (8/1 at 110-116). He argued that the threshold levels needed to be evaluated on a stream by stream basis (8/1 at 64-65).

In Leaf's opinion, the best way to deal with sediment was to keep it out of the streams in the first place, e.g. by leaving buffer strips of vegetation along streams (7/31 at 14-19). In a 1975 USFS publication, Leaf had written that watershed management practices could not prevent normal geologic processes, but the impacts of these processes would not be intensified if watersheds were maintained in good condition (8/2 at 93-95). Trout added that the primary obligation of the Forest Service was management and protection of watersheds. For example, the Arapahoe-Roosevelt forest management plan had identified 11 "critical watersheds" out of 112 on the forest which produced unacceptable sediment yields due to unstable stream channels, clear cutting, and excessive road densities (7/31 at 23-24; 8/2 at 69-77, 85-86).

Walch, a U.S. attorney, argued that maintenance of the stream's channel capacity with instream flows would also maintain the resiliency of the stream to respond to changes in sediment and water flows over a wide range of conditions. He said there would always be sediment entering stream channels, and it would not be entirely eliminated by manipulating the forest as Leaf appeared to be suggesting. The channel maintenance flows were designed to create a condition where the thresholds would not be exceeded even if other activities were permitted such as timber harvesting. Walch argued that if a diversion had pushed the stream near the geomorphic threshold, then management options could possibly be restricted, e.g. by curtailing future timber cutting in the watershed. This would "affect the ability of the Forest Service to provide a continuous supply of timber for the nation" (7/31 at 23-24; 8/2 at 80-81).

Weiss, opposition attorney, objected because the U.S.'s claim was for water supply, not timber supply (8/2 at 82-84). Trout said Walch's implication that the U.S. could cut more timber by taking water away from water users was an "interesting proposal." It was Leaf's opinion that providing channel maintenance flows as a mitigation for bad logging practices, poor drainage or poor planning was "like taking aspirin for cancer"—it treated the symptoms rather than the disease (8/2 at 93-95).

Stream Geometry

Schumm presented a number of graphs of hydraulic geometry relationships using various combinations of bankfull width, depth, cross-sectional area, discharge, drainage area, and sediment sizes. It was the opposition's intent to illustrate the large amount of scatter in these graphs. For example, one plot of slope vs. discharge showed basically no relationship. Schumm said the large amount of variability indicated that:

- the streams were not in quasi-equilibrium or adjustable,
- data couldn't be extrapolated from one stream to another,
- the U.S. definition of bankfull level was very difficult to identify,
- detailed studies at each location would be needed over time to determine channel maintenance flows (Schumm 3/21 at 48-49, 129-134, 136-146; 3/26 at 88-89, 96).

Schumm (3/21 at 137-139) also argued that Leopold's plot of bankfull width vs. discharge at the quantification points might have shown a better relationship than the true situation because bankfull discharge was estimated, and width was one factor used in its estimation.

The State's consultants also prepared longitudinal profiles for several of the WD1 streams. According to Schumm, if a stream were fully adjustable and in quasi-equilibrium, it should have a concave, relatively smooth longitudinal profile and should be able to adjust its slope, width and depth. In general, the WD1 profiles showed a considerable amount of variability and convexities due to "variations in the geologic control." Schumm said the graphs indicated that the profiles had not adjusted to "past history or to the materials" in the channel at this time (Schumm 3/21 at 109-116, 136). Madole explained that large streams like the Platte and Poudre were able to keep up with uplifts which occurred 5 to 10 million years ago. Sharp deflections in the longitudinal profile called **knickpoints** were more characteristic of smaller streams which couldn't adjust to uplifts as rapidly. Some knickpoints were related to faults; others to the location of terminal moraines (Madole 1/23 at 67).

Schumm summarized the results of these analyses by saying, "what we are looking at is a number of channels that apparently have their own individuality. The streams didn't conform to well-established relationships developed by fluvial geomorphologists for streams in quasi-equilibrium conditions. The mountain streams were constrained by material they couldn't transport and this led to great variability in the hydraulic geometry relationships and the longitudinal profiles, indicating that the streams were not in quasi-equilibrium. The streams might still adjust over short distances, e.g. where the banks were easily erodible, but the whole channel would not be considered to be adjusted to its water and sediment flows (3/21 at 126-128, 136, 146).

Harvey elaborated on Schumm's evidence by presenting additional analyses of the hydraulic geometry data. He explained that work had been done by various geomorphologists and engineers to develop the following relationships (4/3 at 671-673):

- **Leopold:** The "Square Root Law" which said channel width was proportional to the square root of discharge.
- **Wolman and Brush**: The boundary (width or wetted perimeter) was proportional to discharge times slope, where the term: (discharge x slope) was called **stream power.**
- **Henderson:** The size of the channel (wetted perimeter) was proportional to stream power and bed material size: $P = 1.14\ QS^{1.17}D50^{-1.5}$, where P = wetted perimeter, Q = discharge, S = slope, and D_{50} = median streambed particle size.

Harvey applied Henderson's relationship to the Forest Service's quantification point data, and found essentially no relationship between Henderson's predicted values and the actual ones. Henderson's relationship did fit some of Leopold and Wolman's data from rivers with fairly coarse alluvium very well. Because it wasn't applicable to the WD1 mountain streams, Harvey believed these streams were not adjusted to bankfull discharge (4/3 at 671-682; 4/10 at 66-68).

During Schumm's testimony, Walch referred to data from an arroyo in New Mexico which showed variability in width when plotted against downstream distance. The width varied from 8 to 20 feet in one area, even though this was obviously an alluvial stream. Schumm conceded that alluvial channels could demonstrate a degree of variability in their hydraulic geometry relationships. However for the WD1 streams, he said the variability reflected a variety of conditions which had nothing to do with hydrology and hydraulics (3/26 at 60-61; 66-69).

VEGETATION ENCROACHMENT

The U.S. and opposition witnesses were in agreement that vegetation encroachment could occur in streams which were dewatered. Schumm gave examples of Great Plains rivers which had adjusted dramatically over a short period of time to their hydrology. He showed a photo of a painting of the South Platte River in the mid-1800's which depicted pioneers fording a river which was a half-mile wide with islands and very little vegetation. A photograph of the same reach in 1957 showed that the river had narrowed dramatically, with a belt of cottonwood trees growing in the old channel. The narrowing was attributed to a reduction in peak flows as a result of reservoir construction upstream (Schumm 3/21 at 75-78; Harner 6/4 at 27-30).

The U.S.'s Viewpoint

Potter presented several principles of plant ecology relevant to stream environments as a foundation for the U.S.'s theory that vegetation would move into the WD1 stream channels if channel maintenance flows were not maintained. He said there was a close interrelationship between plant establishment and a stream's hydrology and geomorphology. For example, the timing of seed dispersal of cottonwood trees was closely related to the peak runoff period. As another example, willows often had adventitious roots which grew from stems - an important adaptation to being covered by water or sediment (1/26 at 44-50).

Potter said plants were influenced by - and in turn influenced - flow patterns and channel form. He summarized the effects of plants on stream processes, giving these examples (1/26/90 at 55-58):

- **Sedges** had triangular stems strengthened by woody tissues which would not easily bend or break. These were of low importance in their effects on stream processes, but would slow water velocities and cause silt and litter deposition in low-flow situations. Higher flows would "blow out the whole system." **Grasses, forbs** and other herbaceous plants such as **horsetails** had similar effects.
- **Woody plants and shrubs such as willows** tended to grow on bars. They reduced water velocities, causing additional deposition of sediment, and they also trapped drifting debris at high flows.
- **Logs** could form a "trap" to catch material moving down a channel. Potter said Leopold had mentioned that log spacing was related to the slope of the stream and the formation of gravel bars. Logs and other debris could have varied effects on the stream channel; e.g. by trapping sediment or causing undercutting when water flowed underneath the logs.

Potter said the best cure for a problem was to "not have the problem in the first place." For prevention and control of vegetation encroachment, the most effective flow regime was the one which had "developed through centuries of time," i.e. the natural flow regime. If water were diverted, it would increase the length of time the stream channel was exposed and thus the growing season (1/26 at 99, 144). It would also lead to higher substrate temperatures which would promote vegetation encroachment. Smaller flows would have less sediment load and lower velocities and would therefore not have the same potential for scouring out vegetation (1/26 at 86-92, 95-97). Potter gave these points in summary:

- It was important to keep the channel covered with water during the growing season. If flows were insufficient to prevent vegetation growth, the plants would become more established each year and more resistant to removal by flooding. Base flows were therefore needed to keep the channel covered with water to prevent encroachment.
- It was undesirable to have a rapid decrease in the falling limb of the hydrograph because it would result in a longer period of channel exposure.
- Peak flows would be needed for controlling vegetation about every 2-3 years.

In Potter's opinion, the U.S. instream flow claims approached the natural hydrograph as closely as possible and would prevent vegetation encroachment (1/26 at 99-102; 10/4 at 49-51). During cross-examination, Potter said it was less critical to provide base flows in November and December, but more critical in September and October. It was his opinion that no base flow had been claimed by the U.S. for late winter or early spring flows in some streams (1/26 at 135-138).

The Opposition's Viewpoint

Harner briefly discussed vegetation impacts on flow, saying that during the peak snowmelt runoff season in early spring, the herbaceous plants were dormant and the willows and other woody vegetation did not have leaves yet, so they offered less resistance to flow (6/5 at 78-84). He said the majority of vegetation in the WD1 channels he had studied occurred right along the top edge of the streambanks, and therefore didn't impede within-bank flows (6/5 at 78-84, 93-94, 110-111).

Harner conducted an extensive literature review on vegetation encroachment, but only found two articles relating specifically to Rocky Mountain streams. One, written by the Wyoming Water

Research Institute on streams of the Rocky Mountains in northeastern Colorado and southeastern Wyoming, concluded that there was little to moderate possibility of vegetation encroachment in those streams (6/4 at 43-52).

Harner cited a number of criteria from Chapter 30 which were to be considered when evaluating whether vegetation prevention flows were necessary or not. These included (6/4 at 30-37):

- the type and size of channel materials,
- channel cross-section shape, whether it was U-shaped (high potential for vegetation encroachment) or V-shaped (low potential),
- availability of seed sources or likelihood of vegetation sprouting,
- length of growing season (the season when the channel was not inundated),
- availability of non-channel water sources capable of supporting vegetation (i.e. proximity to water table and whether stream was losing or gaining),
- water storage capacity of the substrate (i.e. the water storage capacity of sand and gravel was poor in comparison to silts or clays).

From his own observations of the streams studied for the WD1 case, it was Harner's opinion that they weren't "choked with vegetation" in dewatered sections as the Forest Service appeared to be claiming (6/4 at 82). The stream substrates were rocky, lacking in soil and organic matter and low in fertility. Even in areas where all of the streamflow was diverted, water still entered the channels from subsurface flow. Because of these conditions, the plants growing in the channels were stunted in nature with a shallow root system, and survival was low. He showed a photo of a 70-year old spruce tree growing in a channel downstream of a diversion which only had a stem diameter (DBH) of 2 inches, compared to an expected 10" diameter (6/5 at 85-92, 110).

In Harner's opinion, the potential for vegetation encroachment into the mountain streams in WD1 was only low to moderate. Some streams had point bars which he believed might support vegetation (6/4 at 42-43). If base flows were needed to prevent encroachment, he believed the most appropriate time to provide them would be at the beginning of the growing season, i.e. June to mid-July. This would prevent plants from getting started. If they started growing after this period, the season would not be long enough for them to become established. In general, he did not believe either base flows or peak flows were needed to prevent or remove vegetation encroachment in the National Forest streams in WD1 (6/5 at 114-116).

Section 4.
The Character of Streams in WD1

GENERAL DESCRIPTION OF STREAMS

Most of the streams on which the U.S. had filed claims drained high elevation watersheds and were small in size. Only about 5% of the drainage areas above the U.S. quantification points were below 7500 feet in elevation (Walch 4/9 at 146). According to U.S. experts, the median stream width was about 10 feet and the average depth 1 to 1.2 feet (Rosgen 2/13 at 102). Some 41% of the streams had gradients over 4% (Madole 1/23 at 72-73). These numbers were the subject of much debate during the case - not only their accuracy, but whether USGS gauging station sites and U.S. and State study sites were representative of each other or of all streams in the National Forests within WD1.

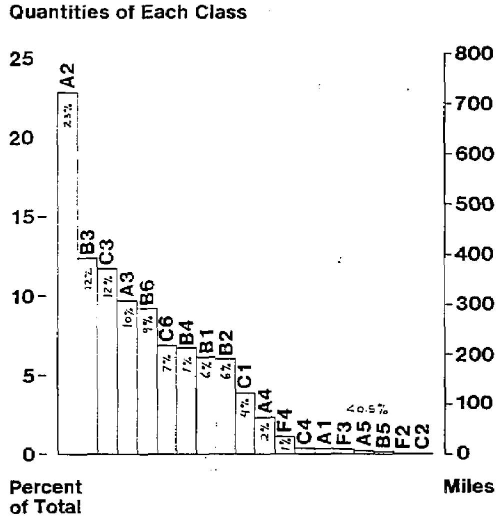


Figure 4.—Percentages of stream types as classified by Rosgen's method. Classification is based on significant lengths of reach which can be identified from topographic maps and aerial photo interpretation. Variation can exist within reaches. From Exhibit [A-707].

The U.S.'s Viewpoint

A classification system developed by Rosgen in 1985 was applied to the WD1 streams. His system integrated a number of variables pertaining to channel adjustment, including the following:

- **Sinuosity**: An index of the degree of meandering, defined as stream length divided by valley length. A ratio of 1 would indicate a straight stream; 3 would be highly meandering.
- **Confinement**: The ratio of floodplain width to bankfull width. The ratio would be smaller in confined streams than in streams with well-developed floodplains.
- **Width to depth ratio:** The ratio of bankfull width to bankfull depth. A lower number indicated a narrow, deep channel and a higher number a wide, shallow river.
- **Particle size of the channel**
- **Soil, land form**

Table 2.—Rosgen stream classification system (simplified). A letter and a number describe the stream, e.g. "A2."

Channel Form	Streambed Materials
A: confined channels, average slope > 4%	1: Bedrock
B: average slope 1.5 to 4%	2: Boulder
C: higher sinuosity, average slope < 1.5%	3: Cobble
E: ephemeral streams	4: Finer gravels, sand
F: incised "channel within a channel" without a well-defined floodplain, average slope > 1.5%	5: Cohesive silts, sand

Straight channels were often associated with steep slopes, coarser bed materials, and a smaller width:depth ratio. As sinuosity increased, streams were typically flatter with finer streambed materials.

In Rosgen's system, an alphanumeric label was given to each stream type, e.g., "A2." These types are described in simplified terms in Table 2. Rosgen's classification system also contained "subtypes" which allowed for variations due to local influences such as beaver dams, riparian vegetation, bar development, etc. However, these subtypes were not used for mapping the streams in WD1 (Rosgen 2/8 at 12-15, 18-35, 69-70).

Over 3000 miles of streams in the National Forests in WD1 were mapped in the fall of 1989, based on aerial observations from a helicopter and slopes obtained from USGS 7.5 minute "quad" maps. Field data from the quantification points was used for verification (Rosgen 2/8 at 38-39). The distribution of stream types is given in Figure 4.

Rosgen made an important point during his testimony that the stream slopes obtained from topographic maps were often steeper than the actual slopes measured in the field. Topographic maps often did not depict the stream's sinuosity in enough detail, particularly for the smaller streams. Rosgen used a procedure of adjusting the stream slopes obtained from USGS maps based on the observed stream type and on aerial photography measurements. This gave values closer to what crews measured in the field. For one example, the USGS map gave a slope of 1.93%, whereas the adjusted value was only 0.8%. Rosgen said if the stream slopes in the "SLA report" (written for the State by Simons, Li and Associates) were based on topo map measurements, they would be overestimated by almost double on the average. Rosgen found that only about 36% of the streams in WD1 were "A" type, with slopes over 4%. It was his conclusion that the quantification points were representative of the stream types in WD1, and that all of these streams were basically adjustable (2/8 at 39-47, 61; 2/13 at 96, 105-107).

The Opposition's Viewpoint

The State's experts maintained that the majority of streams in WD1 were located in narrow valleys and had small widths and very steep slopes. Of the streams they studied (including the WD1 quantification points and streams in Water Divisions 2, 3 and 7), they found that 75% were steeper than 4% (Madole, 1/23 at 72-73, 113-115). Schumm said a slope of over 4% was very steep in comparison to the Mississippi which had a gradient of 1/100 of 1%. He said the WD1 streams and the Mississippi represented "end members" at the extremes of a wide spectrum of stream types (3/21 at 65, 82-83, 110).

SLA researchers did use topographic maps to obtain stream slopes, although some were measured in the field (Rosgen 2/8 at 39-47; 2/12 at 27-28). Mussetter agreed that topo maps didn't provide enough detail to exactly represent the stream lengths; however, he believed most of the mountain streams were relatively straight. The slopes measured in the field by SLA were generally steeper than the U.S.'s values (6/11 at 140-148, 151-165).

As mentioned in Section 3, the opposition described the streams in WD1 as highly variable due to impacts from landslides, glacial debris, log jams, beaver activity, bedrock and other factors. Some 70% of the quantification points were located on streams draining less than 10 square miles. They therefore involved relatively small watersheds high up in the mountains, and channel form was influenced by factors other than hydraulics and hydrology (Schumm 3/21 at 48-49, 61-62, 65-66).

From his review of the Forest Service's quantification point data, Schumm observed that 28 of the channels were dry, 13 were incised channels or gullies which probably developed sometime in the early part of the century, 34 were associated with beaver dams and swampy areas, and about 98 had major bedrock or boulder controls. He concluded that over half of the 244 quantification points had "conditions that make the Forest Service claims irrelevant in this situation, and the bulk of the other ones have no flood plains" (3/27 at 23).

STEP-POOL SYSTEMS

Several witnesses described the smaller headwater streams as "step-pool systems." The "steps" were typically composed of an intertwined pile of boulders and logs where water would flow over the top, around and through the structure. Leaf (8/1 at 74-78) said they frequently occurred in the steeper Rosgen type A and B streams. He called them "nature's way of dissipating energy."

According to Schumm, the **pool/riffle** structures common in plains-type streams were probably formed by the sediments moved at bankfull discharge. **Step-pool** structures were related to higher, more infrequent discharges. He cited several papers which attributed the formation of step/pool structures to flowing water, possibly 500-year flows. In one paper, the authors had found these structures in streams with gradients from 2-10%. At higher slopes, the streams were all boulders; at lower slopes, the step-pool pattern didn't form. Several researchers found that the spacing between *steps* was shorter than the spacing between *riffles* commonly seen in plains-type streams. Harvey gave a range of 0.3 to 2.7 channel widths. Steps were closer at higher gradients. From his own observations, Harvey believed the spacing between structural elements was more random in the mountain streams (Schumm 3/26 at 24-27; Trout 1/25 at 117-118; Harvey 4/2 at 591-592; 9/18 at 96-102; Leaf 8/1 at 81-84, 93-94).

Harvey referred to a journal article by Grant et al.; "Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon." The authors said mountain streams differed from lowland streams because the hydraulics of high-gradient streams were strongly influenced by large boulders "with diameters on the same scale as channel depth or even width." The large-scale form roughness caused high energy losses and disrupted velocity profiles. Floods large enough to restructure the channel occurred only infrequently. In contrast, "geomorphically effective events" occurred more frequently in lowland sand-bed channels (Harvey 4/2 at 523-525).

Walch presented a 1985 paper by Heede which described research on the effect of removing log steps from streams. His hypothesis was that log steps took the place of gravel bars which would otherwise have been required for channel slope adjustments. Five years after all log steps were removed from a stream reach, gravel bars had built up to replace 75% of the logs. Heede believed this proved the hypothesis "that increased bedload movement was required to offset the loss of log steps." He concluded that streamside forests should be managed to provide a steady supply of debris for channel stability (8/2 at 114-117).

Leaf stated that the step-pool morphology was fairly prevalent in the steeper mountain areas. He said this structure was significant in controlling bank and bed erosion, which was the principal source of sediment load to these streams. Therefore if the flow was reduced, he believed the source of sediment and thus the sediment load would also be reduced. The U.S. had not considered the different morphologies and formation processes of step-pool systems when making their claims, and it was Leaf's opinion that they should have (8/1 at 90-93).

The opposition maintained that step-pool structures would not adjust to frequently occurring year-to-year flows. Trout asked Rosgen why instream flows would be needed for some stream types which had step-pool forms and a low potential for adjustment. Rosgen replied that the potential for change downstream of those reaches would need to be evaluated (2/13 at 8-9).

GEOLOGY

The U.S.'s Viewpoint

Madole conducted studies on the geology of the WD1 streams to determine the distribution and ages of surficial materials. In his work, he was looking for evidence of whether the streams in WD1 had formed their own courses or whether they were merely following "paths of convenience" as the opposers had claimed (1/22 at 93-95).

Madole distinguished between **fluvial** which referred to confined runoff in channels, and **alluvial** which was a broader term and included the process of sheet runoff from slopes. Once sediments reached a stream, they could be reworked by fluvial processes. To identify the origin of sedimentary materials, Madole used the following properties (1/22 at 20-21, 128-129; 1/23 at 108):

- **Stratification**; e.g. **glacial till** (material deposited directly by glacial ice, e.g. moraines) was not stratified, but alluvium commonly was. Both sides agreed that most of the glacial till in WD1 was actually fine-grained material, about 70-80% being of sand size or smaller (1/23 at 55; 4/10 at 23). **Glacial fluvial sediment** was alluvial material deposited by melting waters from glaciers, and was typically stratified.
- **Distribution of grain sizes**; e.g. glacial deposits could be composed of a broad range of sizes from clay to truck-sized boulders.
- **Sorting**; e.g. glacial deposits were poorly sorted whereas wind deposits were characterized by a uniform distribution of very fine materials. **Colluvium** was a general term for a deposit of incoherent soil and rock fragments which were transported chiefly by gravity. Rosgen (2/13 at 32-33) gave the example of dry **ravel**, which could occur when soils started to dry after being wetted by snowmelt, and then freezing conditions at night loosened rocks. It mainly occurred in canyons.
- Other properties such as the **shapes of materials**, **arrangement**, and degree to which they had been **rounded**. For example, in landslides, deposits were angular whereas materials tumbled in a stream or abraded by glaciers tended to be rounded.

Harvey (4/5 at 36-38) described **imbrication**, an arrangement of materials indicating fluvial transport. "A-parallel" imbrication was like "shingling" or overlapping of plate-like particles, where the longest axis of a particle was parallel to the direction of flow, and the top of the particle tipped in the same direction as the flow. "A-perpendicular" imbrication occurred when particles were deposited with the longest axis perpendicular to the flow direction, e.g. when they were deposited overbank in a relatively unconfined situation. Imbrication did not occur when particles were spherical. Instead, **clusters** of rocks could occur, typically where a coarser rock was deposited and smaller ones had jammed around it. Imbricated and clustered rocks tended to be stable elements.

Madole estimated that about 15.7% of the total area in the National Forests within WD1 had been glaciated. Even in these areas, he said about 90-95% of the streams flowed within bands of alluvium deposited by the streams themselves. The remainder flowed in bedrock areas or areas of extremely coarse materials from rockfalls, landslides or terminal moraines (1/23 at 34, 50-51). About 2.7% of the area was occupied by landslide deposits, mostly along mountain fronts (1/22 at 23-24; 34). Madole also estimated that 5 to 15% of the area was affected by beaver dams (1/23 at 78-80).

Madole and other U.S. experts described the geologic history of the glaciated areas. During the period of glaciation, large volumes of sediment were produced from glacial erosion. When the glaciers eventually receded, meltwaters reworked sediments and deposited the glacial fluvial sediments as a "veneer" of sand and gravel beds over valley floors. Then, during the Holocene (the most recent 10,000 years), the glaciers disappeared and streamflows generally decreased. The U.S. experts contended that from 10,000 to 2,000 years ago, the valleys were excavated by streams and the older Pleistocene glacial fluvial deposits were left as terraces. Then, from 2000 to 900 years ago, the streams brought in alluvium which built up within the excavations. At 900 years, the streams presently occupying the valley started cutting down into the alluvium and building the present floodplain. Madole said there were actually three periods of climatic cooling during the Holocene when small "surglaciers" formed in valley heads and moved downwards. Leopold said these climate changes were generally world-wide and caused a change in the relationship between precipitation and vegetation cover which controlled erosion. The changes could cause rivers to build up or cut down, in the latter case leaving terraces at the level of former floodplains (Schumm 3/22 at 75-78, 102-110; Leopold 1/24 at 40-43; Madole 1/22 at 17-19; 1/23 at 52-55, 110).

According to the U.S. experts, the formation of new channels within the Holocene alluvial deposits was evidence that the streams had adjusted to present flow conditions. Madole showed a photograph of a terrace about 10 meters tall with an incised channel. The active floodplain of younger alluvial materials within the incised channel had no evidence of soil formation and supported a different vegetation type than the higher, older terrace which had developed a soil profile and was grassed. He concluded that:

- the dominant processes delivering material to the valley floor and channels were alluvial processes,
- the majority of streams in the region were flowing on channels on or in alluvium of Holocene age, not on relic Pleistocene deposits, and
- the streams were formed in—and were flowing on—channels of alluvium that they constructed. They were therefore self-adjusting (1/23 at 10-11, 35-38, 93; 10/4 at 100-104).

The Opposition's Viewpoint:

The opposition contended that the WD1 streambeds were generally composed of very coarse material which would not be moved by frequently occurring flows associated with current hydrologic conditions. They also maintained that much of this very large material had been delivered to its present location by nonfluvial processes, e.g. glaciation, landslides, debris flows, etc. Harvey said Madole's estimate of the extent of landslide effects was too low because many small landslides didn't show up at Madole's scale of mapping (4/2 at 522-569). He also said Rosgen had identified less than 0.5% of the streams as "A1" bedrock controlled channels, but Harvey argued that Rosgen had limited his definition to channels with bedrock boundaries. He believed bedrock outcrops and their influences on stream channels had a wider distribution (4/9 at 15-17, 20-21).

Cohan had done detailed studies of the geology at 10 of SLA's study sites in and out of WD1. She walked the lengths of the streams and correlated observed information with geology maps. Her intent was to determine sediment sources and observe features affecting channels, e.g. landslides. According to Cohan, the advantage of walking the channels was that features not on the geologic maps could be noted. The forest cover was so thick in some places that these features couldn't be seen from the air (3/27 at 57-64). Cohan presented three conclusions from her observations (93/27 at 71-72; 3/29 at 487-488):

- all 10 sites showed some evidence of Quaternary glaciation,
- the largest materials in the channels were not deposited by processes related to the Holocene regime, and these rocks were stable under modern-day flows,
- at every site, the streams flowed over bedrock at some point.

Schumm gave an entirely different interpretation of the geologic evidence in glaciated areas than U.S. witnesses. In his opinion, when the glaciers waned, sediment loads decreased and this caused the streams to degrade and incise below the terraces. Overbank flows carried fine sediments across the valley, building up the floodplains through vertical aggradation - particularly in mountain meadows

(3/22 at 11-12; 3/26 at 19-21). He demonstrated that the upper portion of streambanks was typically composed of finer materials than the streambeds (an "alta-fining sequence"). Schumm believed that the coarser material found in the lower banks and streambeds extended across the valleys and had been deposited by streams during post-Pleistocene glacial melt under a "very different hydrologic condition," or by the glaciers themselves (3/26 at 11-13; 3/22 at 59, 65-66). Harvey argued that either the Forest Service's "terraces" were really floodplains, or the channels had changed their nature in the Holocene to cause the modern floodplains—the tops of bars—to contain only coarse materials. He said Wolman and Leopold had estimated vertical aggradation rates at 1 mm/yr; therefore the 20-30 cm of fine-grained materials on the "terraces" would have taken a long time to build (4/2 at 559-565; 4/3 at 733-754; 4/10 at 15).

Because the maximum width of recent alluvium was only 150 feet on the Cache la Poudre, one of the larger rivers, Schumm said this meant that the river hadn't moved laterally any more than 150 feet since the streams began downcutting. He concluded that the WD1 streams were therefore very stable and hadn't changed their positions in at least 1000 years despite forest fires, climatic fluctuations and human activities (3/21 at 149-152).

THE OPPOSITION'S POSITION THAT CHAPTER 30 DID NOT APPLY TO THE WD1 STREAMS

Opposition witnesses did not believe Chapter 30 properly applied to the WD1 streams because it was based on theories derived from studies of plains-type streams with large drainage areas, flat gradients and fine-grained bed materials. They believed the mountain stream channels in WD1 were relatively small, steep, and coarse-grained, and many of the major structural elements would not be transported by the flows claimed by the Forest Service (Simons 4/11 at 77-79, 146-147; Li 6/7 at 76-78; Schumm 3/22 at 45-46, 61; Harvey 4/3 at 683-687). Harvey said Chapter 30:

"violates one of the fundamental tenets of extrapolation . . . that . . . you don't extrapolate beyond your database" (4/2 at 527-534; 4/5 at 63).

Simons described the relative morphologies of mountain and plains-type streams as follows:

- **plains-type streams:** In these streams, streambeds were composed of small sand grains which did not affect the flow individually, but could form major features such as riffles, dunes and bars which significantly affected flow resistance. Bed features and velocity distributions could therefore change with stage. Sand bed streams usually had an extensive floodplain with natural levees on the banks. The streams were typically meandering or braided.
- **mountain channels:** In the small, steep, cobble-boulder bed streams, normal meandering and braiding patterns didn't occur. The banks and bed resistance were related to other geologic and geomorphic controls such as logs, beaver dams and coarse rocks. The streamflows also fluctuated less because the mountain streams were fed by snowmelt. Simons said the biggest difference between the two types of channels was that there was "not nearly the dynamic response between the sediment being carried in the channel with increases in discharge" in the mountain streams. Decreases in flows would not have the same impact as in plains streams (Simons 4/11 at 56-58).

Another major argument concerning Chapter 30 methods was that some of the U.S. quantification points had been classified as "E" type streams—for "ephemeral." Harvey said most of the literature he was familiar with said ephemeral flow channels were adjusted to the last flow experienced (4/2 at 640-645; 4/3 at 664-670). Chapter 30 contained the statement (Section 31.11):

"At present the procedures can only be applied to watersheds where streamflow is perennial and dominated by snowmelt runoff. Methods applicable to rainfall dominated perennial and ephemeral and intermittent streamflow have not yet been developed."

Rosgen explained that the Forest Service had developed modified procedures for ephemeral streams for the WD1 case. Instream flows were being claimed in WD1 on at least 10 ephemeral streams. There was no base flow claim for these streams (Rosgen 2/12 at 51-56).

Section 5.
Field Data Collection and Analysis

When the Forest Service contacted Leopold in 1988 about the WD1 case, they discussed the following issues (1/24 at 9-16):

- The limited amount of literature on fluvial processes in high mountain areas and the need for new data, particularly on bedload.
- Field measurements and computation procedures needed for quantifying instream flows.
- The need to establish sites for the study of fluvial processes. Preferably, the sites would represent a wide variety of stream types and be located near USGS gauging stations.
- Diversion studies for comparing conditions above and below diversions.

An extensive amount of effort went into the collection of field data on the Colorado mountain streams. The U.S. collected site-specific channel geometry data at 244 quantification points, detailed streamflow and sediment measurements at 9 fluvial process sites, and physical and vegetation data above and below 13 diversion sites. The State repeated many of the same measurements at these same sites as well as others.

Both sides criticized the other's field data collection and sampling procedures as giving biased and/or unrepresentative values. The opposition claimed that the data and methodologies used by the U.S. did not describe the highly variable WD1 streams or accurately quantify the minimum amount of water needed for channel maintenance.

U.S. STUDY SITES AND FIELD PROCEDURES

Quantification Points

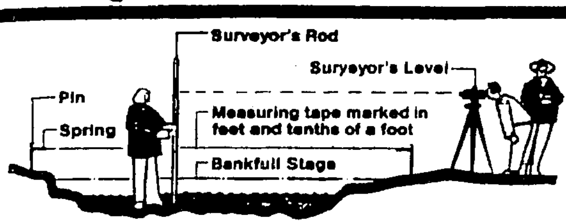
In order to develop the instream flow claims, the Forest Service established "quantification points" which represented the locations of claims on each stream. Field measurements at the actual sites were considered preferable to extrapolation or correlation methods for litigation purposes (Leopold 1/24 at 18). Several hundred quantification points were initially established on the National Forest streams within WD1 for the 1984 claims. These points were chosen to provide as much coverage of the system as possible, within constraints of time and access. In the process of developing the 1989 amended claims, many points were deleted or moved for various reasons. Silvey (1/29 at 161) testified that the changes were made "to take into consideration the water rights of others." The 1989 claims were made at 244 quantification points. Flows were claimed on streams where a discernible channel was present, even in ephemeral streams. If a channel was more of a "grassed swale," no instream flow was claimed (Rosgen 2/13 at 108-109).

Data Collection at Quantification Points

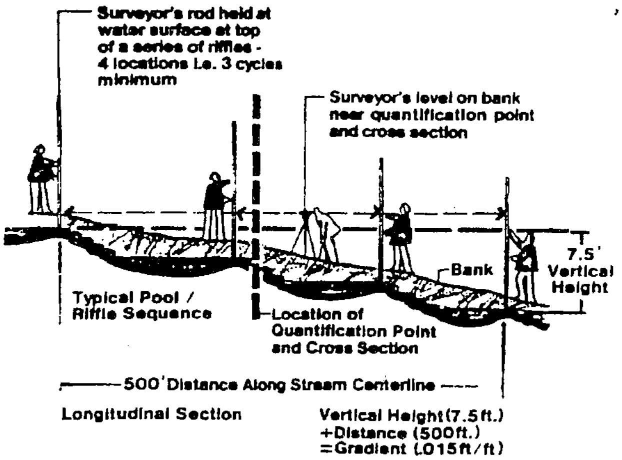
Quantification of the U.S. channel maintenance claims required field data at all 244 quantification points. Published and field data were also collected at USGS gauging stations in or near WD1. Figure 5 describes some of the terms and procedures. The following data were collected for each quantification point (Silvey 1/29 at 5-43):

- <u>Drainage basin area</u>
- <u>Weighed mean elevation of drainage area</u>: a watershed was divided into elevation zones using a topo map, and the area and mean elevation of each zone was computed. An area-weighted mean elevation was then calculated from these values.
- <u>Elevation of quantification point</u>
- <u>Cross-section surveys:</u> cross-sections were located by field crews in "what they interpreted to be a typical reach, usually a straight section" (Silvey 1/29 at 10). The reaches were typically hundreds of feet in length (Leopold 1/24 at 155-157). <u>One</u> cross-section was established within the reach by marking it with two stakes. This was surveyed with a level, rod and tape after identifying bankfull level. Measurements were typically taken every 0.5 foot, with more taken in irregular and less in smooth channels, in an effort to reproduce the wetted perimeter as precisely as possible. From cross-section information, values were obtained for: <u>bankfull width</u>, <u>mean bankfull depth</u>, and <u>width:depth ratio</u>.
- <u>Stream gradient</u>: the <u>water surface slope</u> of the stream reach at each quantification point was measured using a level, rod and measuring tape.

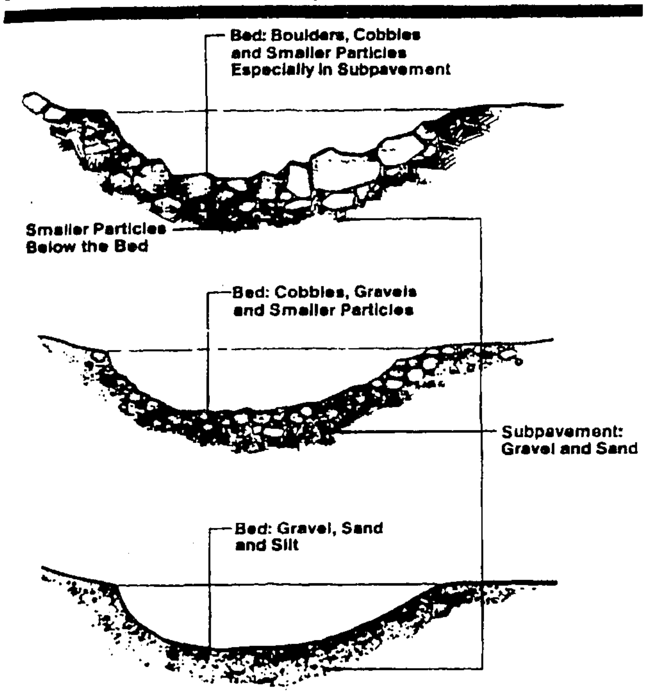
Measuring Stream Cross Section



Measuring Stream Gradient

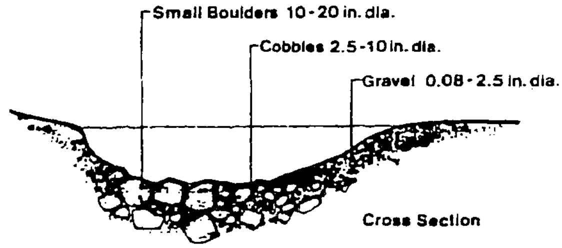


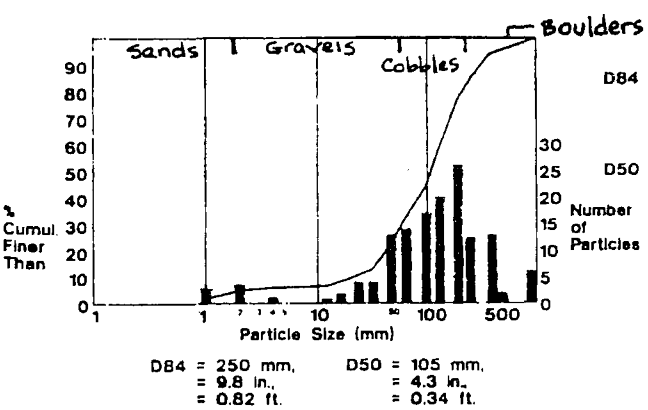
Bed Material and Subpavement Material



Particle Size and "D"

"D50=20mm"
Means:
50% of the Particles measured are equal to or smaller than 20mm diameter (based on a pebble count.)





Sediment Particle Sizes

Class Name	Millimeters	Inches
Boulders	4,096 - 256	160 - 10
Cobbles	256 - 64	10 - 2.5
Gravel	64 - 2	2.5 - .08
Sand	2 - .062	0.08 - .002
Silt	.062 - .004	less than .002
	.004 - .00024	less than .002

Figure 5.—Field data collection: terms and procedures. From Exhibits [A-505 and 507].

- **Bed material:** streambed surficial materials were sampled within a representative portion of the channel below bankfull level using Wolman pebble counts. With this method, a field crew member would randomly take a step, pick up a rock or substrate sample without looking, measure the intermediate axis and record the measurement. Larger particles over about 2 mm were measured directly; finer materials were estimated visually and by feel.

  Particle size distributions were graphed as "cumulative percent finer" against "particle size." The D_{84} and D_{50} values for each site were obtained from this graph, representing the particle sizes for which 84% and 50% of particles were smaller, respectively.
- **Channel classification**: determined from Rosgen's method of stream classification. Field interpretations were made to classify land form and soils as colluvial or alluvial and to identify sources of bed materials.
- **Photographs**: taken at cross-section sites to show site conditions. Typically, four photographs were taken: left and right banks, upstream and downstream views.
- **Discharge**: it was unclear from Silvey's testimony whether discharge was measured at quantification points, although he presented an exhibit showing how it was measured with a current meter.

Field data were collected by experienced Forest Service hydrologists, hydrologic technicians, biologists, geologists and engineering technicians. Rosgen conducted a 2-day training session for field crews in 1989 to cover surveying techniques.

Forest hydrologists entered data onto computer spreadsheets. Several methods were used to check the data, such as by plotting the results. Most of the errors found were relatively minor, such as an incorrect date (Stuart 2/6 at 107-108).

FLUVIAL PROCESS STUDY SITES

Special study sites were established in order to obtain much-needed data on sediment, discharge and channel geometry in mountain streams. A total of 9 streams with a variety of gradients and particle sizes were selected by the U.S. for these fluvial process studies. Sites were selected which were near USGS gaging stations. The percentage of stream miles within WD1 represented by the sites was about 60%, based on stream type (Rosgen 2/8 at 78-79; Leopold 1/24 at 119; Chavez 2/5 at 129-130).

Rosgen (2/8 at 79-83) said the purpose of these study sites was to:

- Characterize the channel, e.g. its geometry, bankfull discharge, etc.
- Study the variability and distribution of bedload and suspended sediment loads which would move under different flow conditions and during different seasons.
- Monitor discharge continuously at some sites to develop a discharge hydrograph over the field season.
- Determine the adjustability of the streams, i.e. whether the bed and banks eroded, and if so, under what flow conditions.

Field Data Collection at Fluvial Process Study Sites

Field data were collected at the 9 fluvial sites over the 1989 summer field season. As for the quantification points, representative reaches of hundreds of feet in length were selected. Benchmarks were established and the following information was collected (Chavez 2/5 at 104-130; Leopold 1/24 at 120-122; Rosgen 2/8 at 83-84, 106-110, 172-173, 178; 2/9 at 80-84; 2/13 at 148-149; 2/14 at 17-18):

- A detailed map at 1"=20' scale was developed using a plane table. Mapped features included bars, debris dams, logs and locations of cross-sections. Cross-sections at one or more locations within the reach were surveyed, including identification of bankfull level.
- Longitudinal profiles of the streambed and water surface were surveyed with a rod and engineering level. Water surface elevation was measured using a modified rod with a hook on it which could be slid up or down to just touch the water surface.
- Discharge was measured using USGS procedures. A cross-section was divided up into as many as 20 sections, and velocity was measured within each sub-section using either a Price AA current meter in larger streams or a Pygmy current meter if streams were shallow and velocities less than 3 ft/sec.

  A staff gage was also installed at each fluvial site, from which a rating curve could be developed by relating the staff gage reading to discharge measurements each time the site was visited. Recording gages with pressure transducers were established at some sites which recorded stage each 15 minutes. Discharge hydrographs for the

May-September field season were developed from these data.

- Surface bed materials were sampled using Wolman pebble counts. Transects covered the same area where bedload measurements were taken. The transects crossed both pools and riffles in order to obtain a representative sample.
- Samples of bars were taken at each fluvial site. These were collected at approximately 3 locations on an individual bar, by setting a bucket with no base (a "bottomless bucket") onto the sample site and collecting everything within it to some depth. The samples were sent to a lab for particle size analysis.
- Subsurface materials were sampled in riffle areas with the bottomless bucket (12" diameter for smaller materials, and 2-2.5' for larger). The surface particles were first removed, and then about 2" of the underlying material was collected, bagged and taken to a laboratory for analysis.
- Suspended and bedload sediment were both measured at the same cross-section as the discharge measurements.
  - Suspended sediment was measured with a standard USDH48 sampler which sampled to within 3" of the streambed.[2] "Integrated" samples were taken at several locations across a cross-section by lowering and raising the sampler through the water column. The water/sediment samples collected in bottles were analyzed to determine sediment concentrations.
  - Bedload sediment was measured with a **Helley-Smith sampler**, which had a square opening and a bag to catch the sample, and could be placed right on the streambed. Both 3" and 6" samplers were used. The sampler was left in the stream for 4 minutes per sample to catch materials moving downstream. This was increased from 2 minutes based on a recommendation from Andrews that the longer sampling period was more representative because of the random movement of bedload materials. At high flows, the sampler was left in for a shorter period to keep the sampler from filling up.

    Samples were taken at 10 points across a cross-section. Each sample was bagged separately and sent to a laboratory for particle size analysis. The largest rock caught in each sample was measured in the field.

    A larger **instream bedload sampler** ("basket" sampler) with a 2-foot square opening was anchored on the streambed and checked every day in order to collect larger particles than what could be caught with the Helley-Smith sampler. At one site, this sampler trapped a 238 mm particle, whereas the largest particle captured by a 6" Helley-Smith sampler was only 80 mm.
- A "painted rock study" was conducted at each site to observe which sizes of particles moved at which flows. From the Wolman pebble counts of surface materials, the D_{35}, D_{50} and D_{84} sizes were calculated. Rocks of these sizes were then collected from the sites, painted, and placed in rows across the channel - one row for each size. Not all sites had a "D_{35}" line because the particles were so small that they moved very easily.

  Rock lines were examined almost every day, particularly during and after high flows, to see if any had moved. An "invention with a glass bottom" was used to observe rocks when the water was very turbid. Records were kept of the distance and the number of times individual rocks moved.
- A bank erosion study was carried out in order to examine rates of lateral adjustment and conditions favoring it. Rosgen had developed a rating system to evaluate the potential erodibility of streambanks based on the inherent erodibility of the bank itself and the shear stress of the water impinging upon it.

Bank erodibility:

- Rosgen developed these criteria for assessing bank erodibility (2/9 at 74-78):
  - Bank height/bankfull height ratio: More bank height above bankfull meant a higher potential for erosion due to undercutting, exposure to freeze/thaw, collapse, and fluvial entrainment of particles.
  - Bank angle: The flatter the angle, the lower the susceptibility to erosion
  - Density of roots: This was measured as a percentage of bank height, e.g.,

[2] *Richardson (7/24 at 187) mentioned that the USDH48 sampler was developed in 1948. He used Wyoming in 1989 to study sediment inflow to Boysen Reservoir.*

grasses wouldn't root as deeply as willows. The higher the density, the more bank protection; 10% was low and 50% high.

- Soil stratification: any interface between strata meant higher potential for erosion. A bank with many clay lenses or many layers of different materials would have high potential.
- Particle size: large rocks, boulders, and cobble would represent low erodibility, as compared to sand and gravel which would represent high erodibility. Arrangement of the particles was also a factor.

Shear stress:

- The procedure for evaluating the amount of stress applied to the streambanks by water basically involved dividing up a cross-section into thirds of the width and computing the flow through each third. If the flow was fairly evenly distributed across the stream, it indicated a low stress condition, whereas if most of the flow was in the sub-section near a bank, it was a high stress condition.

"**Velocity isovels**" were developed by measuring up to 10 profiles across the section at medium stage, with at least 5 vertical measurements at each profile. From this, the velocity distribution could be plotted like a contour map, where the "isovels" were lines of equal velocity. As they grouped more tightly the velocity gradient increased. If this occurred near a streambank, high shear stress was exerted on the bank.

To study the relation between Rosgen's rating and actual bank erosion, cross-sections were established both in straight and meandering reaches at the study sites. "Erosion pins" (Two-foot sections of rebar less than ½" diameter, painted orange) were hammered into the bank, leaving 0.2' of the rebar exposed. The amount exposed was measured periodically to determine how much of the bank had eroded. A "toe pin" was also imbedded in the streambed near the bank with the erosion pins, and the distance from it to the bank measured using a rod and a tape. Measurements were taken at least twice over the season.

Field crews were trained in data collection procedures by Rosgen before going out into the field. Chavez commented that the data collection effort was extremely intensive, with over 15,000 hours spent in sampling and analyzing data from the 9 fluvial sites. Over 220 stream discharge measurements were taken during the runoff season (Chavez 2/5 at 129-30).

Studies at Diversion Sites

Studies were conducted in reaches upstream and downstream of diversion sites to determine whether differences might exist due to the presence of the diversion. The diversions varied in age from about 42 to 127 years. Diversion sites were selected which:

- had been in existence for a long time,
- were reasonably accessible, and
- represented stream conditions in the mountains of WD1.

A total of 23 diversion sites were selected. Many of the diversion sites were outside of WD1. They were generally above 9000', in subalpine regions with spruce/fir forests (Silvey 1/31 at 50-51, 62-67; 2/1 at 40; Walch 4/10 at 88-90; Harner 6/4 at 21).

Studies were conducted at the diversion sites in 1988 and 1989. Data were collected on physical characteristics, vegetation density, and tree rings, and were summarized in the "diversion study data book." Figure 6 is an excerpt from the data book [Exhibit A-518].

Physical Data

Cross-sections were established above and below diversions in relatively uniform sections without tree jams, large rocks or logs. Rather than using uniform or random placement of cross-sections, judgment was used to select cross-section locations best suited for assessing the potential for channel change due to the presence or absence of flowing water. For 12 out of the 23 diversion study sites, more than one "above/below" pair of cross-sections were compared. Pairs of cross-sections were selected from meandering reaches upstream and downstream as well as from straight reaches (Silvey 1/31 at 62-67; 2/1 at 40).

Data collected for the above/below studies were similar to data collected at the quantification points and fluvial sites, including (Silvey 1/31 at 53-59; Potter 1/26 at 34-40; Jacoby 1/29 at 128-129):

- summary information of drainage basin area, mean elevation of the basin, elevation of the diversion structure, initial date of diversion, and summary of operational hydrology,

- photos of the diversion structure, conveyance ditch leading from it and views of the stream above and below the structure,
- a map showing the location of cross-section measurements,
- physical data including cross-section measurements (from which bankfull width, mean bankfull depth, bankfull x.s. area, width/depth ratio and wetted perimeter were obtained); stream gradient; pebble counts of surface materials, and samples of subsurface materials. D_{84} and D_{50} values of the streambed material sizes were obtained.

Different "bankfull" levels were measured above and below diversions:

- *Above the diversion*, the current bankfull level was evaluated.
- *Below the diversion*, field crews looked for:
    - a "new bankfull" mark corresponding to the existing active channel, and
    - an "old bankfull" mark representing the remnants of the former channel which existed prior to the diversion.

The "current bankfull" cross-sections above the diversions were compared to the "new bankfull" cross-sections below the diversions to evaluate the response of the channel to the diversion.

Vegetation Measurements

The principal purpose of the vegetation studies was to determine whether reduced flows below diversions lead to **vegetational encroachment** in channels. Potter defined **vegetational encroachment** as the movement of vegetation from one area into another, and its successful establishment in the new location (1/26/90 at 28, 59).

South St. Vrain Creek Diversion Site
Comparison of Channel Characteristics
Above and Below Diversion, Straight Reaches

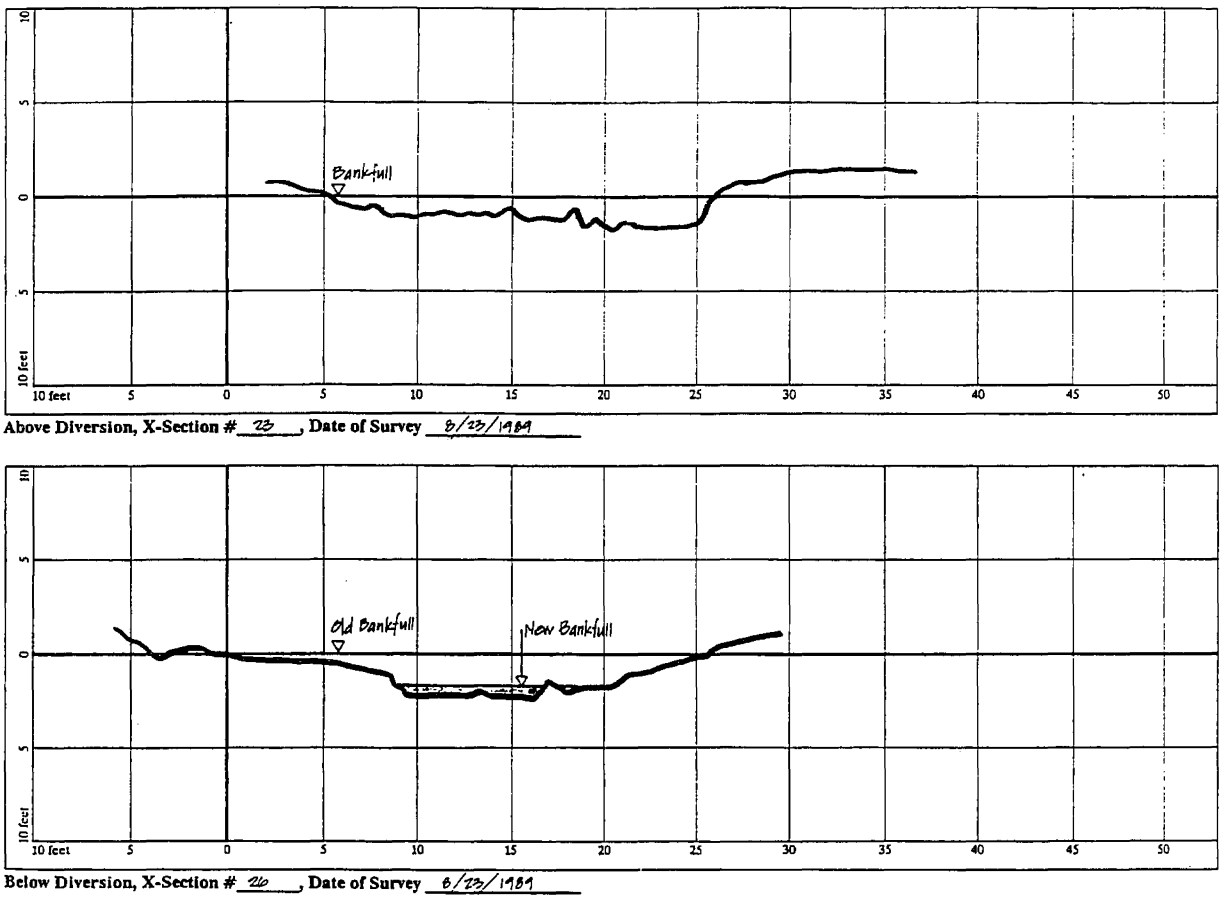


Figure 6a.—Channel characteristics at a U.S. diversion site, the South St. Vrain. From exhibit [A-518].

Data were collected in 1988 and 1989 at the same sites where physical data were collected by the Forest Service's hydrology crews. Not all of the sites were visited due to time restrictions. Potter collected the following data:

- Photographs of above- and below- diversion conditions
- Density of herbaceous and woody plants less than 3′ tall, measured using both line transect and quadrat methods
- Density of vegetation taller than 3′, measured with 3′ quadrats
- Texture of bed material along the transects, grouped by general category (e.g. gravel, cobbles, boulders, sand and clay)

Sampling locations were different above and below diversion sites:

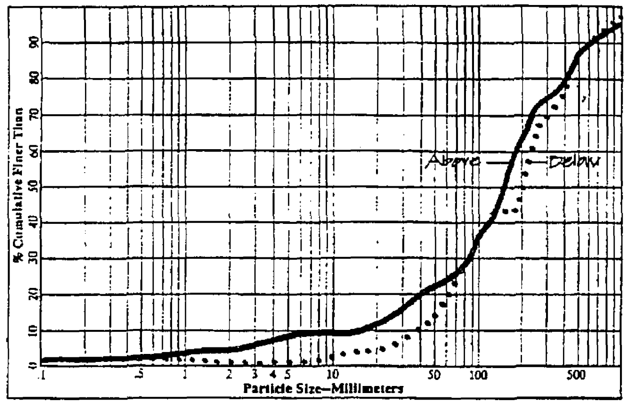
- ***Above the diversion:***
  - from bankfull line to a point 6 feet back on the upland side,
  - from bankfull line to edge of water.
- ***Below the diversion:***
  - from "old bankfull line" to 6 feet back on upland side,
  - from "old bankfull line" to "new bankfull line."
  - from "new bankfull line" to edge of water

Potter believed that woody vegetation—trees and shrubs—would have the effect on channel morphology, and most collected data separately for this vegetation type (1/26 at 41). Foliar cover was measured rather than basal area because in Potter's opinion, a plant's effect on flow resistance was related to the spread of the plant rather than the basal area. Researchers did record whether the vegetation was rooted in the channel or not (1/26 at 25-6).

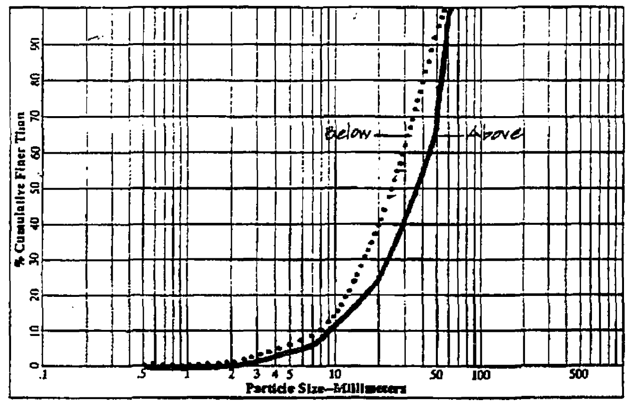
Potter collected data on foliar cover at 16 different streams, giving a total of 30 paired sets of transects. At least one set was located at a hydrology cross-section. Sites upstream and downstream were also surveyed if time allowed. For all of the 1989 study sites (6 sites), the hydrology and vegetation crews were at the study site at the same time; for the other 10 streams, the hydrology crew had surveyed in 1988 and the vegetation crew in 1989. For those sites, the vegetation crew was accompanied by a Forest Service hydrologist (Potter 1/26 at 37; 10/4 at 17-24).

These sampling techniques were used:

- "Slack tape" line transect sampling: a tape was placed along the ground, following the surface topography and extending horizontally across the existing water surface. If the channel was dry, measurements were made across the entire wetted perimeter. The foliar cover intercepted by the tape was measured in hundredths of feet. Vegetation was separated into growth forms: grasses, grass-like plants (e.g. sedges, forbs), shrubs less than 3′ tall, trees less than 3′ tall, and overlap (e.g. shrubs over grasses). Total foliar cover (as a linear distance in feet) was calculated as the sum of all intercepted vegetation minus the overlap. Data were expressed as percent cover by category (Potter 1/26 at 23-24, 32).



Bed Material



Subpavement Material

Site Characteristics at X-Sections		Above Diversion	Below Diversion
• Stream Gradient		0.034 ft./ft.	0.025 ft./ft.
• Bankfull Width		20.8 ft.	9.7 ft.
• Bankfull X-Sectional Area		22.6 sq.ft.	4.19 sq.ft.
• Mean Bankfull Depth		1.09 ft.	0.43 ft.
• Bankfull Width/Mean Bankfull Depth Ratio		19.1	22.5
• Bankfull Wetted Perimeter		24.14 ft.	10.61 ft.
• Bed Material Size	D84	500 mm.	480 mm.
	D50	150 mm.	205 mm.
• Subpavement Material Size	D84	52 mm.	45 mm.
	D50	35 mm.	25 mm.
• Change in Bankfull X-Sectional Area		-81%	

Figure 6b.—Channel characteristics at a U.S. diversion site, the South St. Vrain. From Exhibit [A-518].

- Quadrat sampling with a 1-foot square frame: The frame was divided with cross-wires into 100 squares, and was placed at 1′ intervals along the same transect as the line transect sample. The percent foliar cover was *estimated* at each placement. Litter and moss were recorded as separate cover measurements. The quadrats were also used for estimating percent cover of surface materials in order to relate vegetation invasion to texture. Data were expressed as percent cover by category (Potter 1/26 at 26-29).
- Quadrat sampling with a 3-foot square frame: This frame was used for inventorying vegetation taller than 3′. The number of plants inside each 3′ quadrat were *counted.* Plants were divided into classes by species and by stem size category (1/2″ intervals). These results were expressed in terms of number of individuals/unit area, and standardized to a 100 square foot area.

THE OPPOSITION'S DATA COLLECTION EFFORTS

SLA Study Sites

The State conducted its own stream surveys to characterize the nature of stream channels in the Colorado National Forests. Because U.S. claims had initially been filed in Water Divisions 1, 2, 3 and 7, the State of Colorado asked its consultants to study streams in all four areas. Results were contained in the "SLA Report" produced by Simons, Li and Associates.

SLA had studied some 48 sites which were selected as being representative of the range of conditions present in National Forest streams within the four water divisions. Sites were selected from the U.S. quantification points in those areas. Drainage area and stream gradients determined from maps were the primary criteria for selecting a representative set of sites. Fifteen sites out of the 48 were in WD1 (Mussetter 6/11 at 62-66, 148; Simons 4/11 at 82-83).

SLA field crews located U.S. quantification points on the ground using the Forest Service's description. At the time, the Forest Service had not started collecting field data and the sites were not marked. SLA collected the following data for the State (Mussetter 6/11 at 72-100; 6/12 at 60-62; 6/20 at 144-153; 6/21 at 94-96; 6/25 at 18-19):

- A plan view sketch of the study reach was drawn, and photographs of each cross-section were taken.
- Cross-section sites were selected at locations which were representative of the stream in that reach. Relatively straight sections were selected whenever possible, although some were located in bends. The field crews located and marked 3 to 5 cross-sections at each site, spaced at 100-300 foot intervals. These were surveyed using a surveyor's level, surveying chain and rod. Measurements were taken at slope "breakpoints" and at changes in vegetation or streambed characteristics. Field sketches of the cross-sections were also made.
- Slope was computed from the distance and elevation change between cross-sections. The elevations of the cross-sections along each study reach were tied together by surveying from one to the next, and a "level loop"—a survey back to the starting point—was done as a check.
- Wolman pebble counts were made on surface materials. The sampling sites were normally in riffles or in the interface between a riffle and a pool where bed materials were coarser. These sites were chosen because the riffles controlled the gradient of the stream and its vertical adjustability. SLA also used photographs at 3 sites to "enhance" the Wolman pebble counts by estimating the distribution of boulders.
- Bank material was grab-sampled using a shovel. Samples were collected from bars if it appeared that the gradation was different from that in the streambed. A 2′ square grid with strings crossing at 0.2 foot intervals (set on the ground) was sometimes used to analyze the gradation of surface samples.
- Bedload samples were collected with a 3″ Helley-Smith sampler. A 20 minute sampling period was used at most sites (6/11 at 96).
- Suspended sediment samples were taken with a USDH48 sampler, which was designed to sample the water column above 3″. Richardson's team also collected sediment data at sites within WD1 using the same procedures (7/26 at 135-138).
- Discharge measurements were taken using a Marsh-McBirney electromagnetic current meter, set at six-tenths depth from the water surface (standard USGS procedure for water depths 2.5′).

In 1986, ten out of the 48 sampling sites were visited 5-6 times each; the remainder were visited 2 times each. The purpose of multiple visits was to have a range of discharge and sediment transport data, and to observe changes in the stream channels (Mussetter 6/11 at 101-102).

SLA suspended its analysis of data in 1986-1987 while waiting for the Jesse decision in the fall of 1987. They then collected additional data in a similar manner in 1988. At this time, SLA still did not know which water division in which the case would be tried, so they continued to work in all four divisions. They decided to collect additional data on vegetation and geology in addition to hydraulic and sediment transport data. A total of 26 sites were visited in 1988, 19 of which were from the 1986 data collection program. Additional studies were done at quantification points near diversions, and at USGS gaging stations. The final version of the SLA report, which contained summaries of the field data and analyses, was published in January, 1989 (6/11 at 102, 122-126).

Diversion Studies

The purpose of the State's diversion studies was to evaluate the factors controlling the form of stream channels above and below the diversions, and to evaluate the adequacy of the U.S. data collection program. They believed that a limited number of cross-sections above and below diversions wouldn't indicate whether the diversion was in fact causing downstream impacts. They also observed that at many of the diversions, the geologic/geomorphic setting was very different upstream and downstream of the diversions, and this wasn't sufficiently addressed by the Forest Service's data collection program (Harvey 4/3 at 698-699).

The State studied the same streams as the Forest Service. A total of 13 streams with 14 diversions were investigated in 1989 by the State (Cohan 3/27 at 73).

Location and Number of Cross-Sections

The State's team collected data at 20 cross-sections at uniformly-spaced locations both above and below the diversions. Cohan explained that although this was the goal, it was not always possible because of beaver ponds or because the channel was so steep as to be hazardous. Cross-sections were spaced at a uniform distance of 5 times the channel width - typically 40-50 feet, but up to 100 feet in some streams. Cross-sections established by the Forest Service were also surveyed for bankfull width (Cohan 3/27 at 98; Schumm 3/27 at 74-77, 134-135).

Physical Data

The State's field crew usually consisted of a team of 5 researchers: two geologists, geomorphologists or engineers to collect physical measurements, and three ecologists to collect vegetation data. In the field, the ecologists and geologists worked together and coordinated their measurements, taken as follows (Cohan 3/27 at 74-83, 86-93, 115-124, 195-196; 3/28 at 205, 234-239, 276-278; 3/29 at 389-390, 400):

- <u>Distance from the diversion</u> was measured with a hip chain (a roll of thread with a measuring device to measure how much thread has been pulled out). The end of the hip chain was tied to the diversion structure.
- <u>Cross-section surveys</u> were made by first marking bankfull location at the break in slope at the tops of banks with non-permanent orange spray paint. Bankfull depth (in the deepest part of the channel) and bankfull width were measured with a tape stretched horizontally across the channel and a stadia rod. If the banktops were uneven, the first break in slope (lower bank) was used and the tape stretched horizontally across the channel from that point. The horizontal position of the one maximum depth measurement was not recorded.
- <u>Slope</u> between cross-sections was measured using an inclinometer and a stadia rod marked at the eye height of the person with the inclinometer.
- <u>Channel direction</u> was measured between cross-sections with a Brunton compass. Walch later brought out that the State's team had not followed the standard engineering survey procedure to "close the loop" in order to check the compass readings.
- The <u>widths of the three largest rocks</u> (clasts) within 1' of the horizontal tape were measured at each cross-section.
- <u>Plan view maps</u> were prepared by Cohan from the field measurements, sketches and observations—29 in total. Mapped features included cross-section locations, undercut distances, bedrock outcrops, alluvial fan deposits, logs, cobbles, boulders, the size of boulder or log "drops," and the sizes of trees measured by the vegetation team. A line drawn down the middle of the channel indicated the channel direction taken from compass readings. The cross-sections and

distances between them were drawn to scale (generally 1″ = 10′, some 1″ = 20′), but other information was schematic in location and size.

After the field surveys were completed, the data were reduced into notebooks and Lotus 1-2-3 spreadsheets. Streambed elevations at cross-sections were plotted against distance along the channel to obtain a longitudinal profile of the deepest part of the channel (Cohan 3/27 at 89-91).

Vegetation Data

Harner read this definition of **vegetation encroachment** from Chapter 30 (6/4 at 24-26):

> *"The tendency for vegetation to become established in areas normally devoid of such occupancy, specifically perennial vegetation growing within the active channel (for example, on bars or in the thalweg)."*

He said this definition had remained consistent throughout the various drafts of Chapter 30.

The State conducted its own vegetation surveys at the diversion sites. They also believed woody plants would have a more significant effect on water flow than moss and herbaceous vegetation, and therefore concentrated their efforts on evaluating trees and shrubs (Harner 6/4 at 73-81).

The three vegetation experts worked behind the researchers collecting physical data. Generally, ½ day was spent above the diversion and ½ below. The vegetation crew counted all woody vegetation within the State-defined bankfull levels except at four sites where the vegetation was too abundant to be totally enumerated during the allotted time. At those sites, the crew sampled within smaller quadrats. Vegetation data were recorded for each segment between the hydrology cross-sections. On occasions where the ecologists were uncertain whether a plant was within or outside the bankfull lines, they would ask the engineers for interpretation. If bank heights differed, which was rare, they included all plants within both bank tops. This would increase the number of plants counted, but Harner argued that the chances of having uneven bank heights would be the same upstream and downstream of the diversions (Cohan 3/27 at 78-79; Harner 6/4 at 91; 6/5 at 25-27).

Woody vegetation was separated into size classes, based on "**DBH**", the diameter at breast height, 4.5′ above the ground measured with a DBH tape calibrated to read diameter. This was a standard for measuring temperate zone trees (Harner 6/4 at 12). These size classes were used:

- <u>Greater than 1 inch DBH</u>
- <u>Less than 1 inch DBH</u> - which was further divided into 4 sub-categories, based on basal diameter (the diameter of a stem where it came out of the ground):
  - A class, 0- ½″
  - B class: ½-1″
  - C class: 1″-1 ½″
  - D class: greater than 1 ½″

For multiple-stem plants, each stem was measured and added to give the basal area of the whole plant (Harner 6/5 at 6-8).

At the four locations where the field crew sampled woody vegetation rather than doing a total enumeration, they created a smaller quadrat by taking 10% of the segment length (the distance between cross-sections), centered around each cross-section. For these quadrats, they only counted woody stems less than 1″ DBH; the larger stems were still counted in total for each segment (Harner 6/4 at 87-88).

In addition to the other data, the vegetation crew made notes and estimates of the percent coverage of algae, moss, herbaceous material, rocks, water in the channel, and "suitable substrate" (particles 2 mm or less, i.e. sand, clay and silt). They also recorded other ecological observations such as evidence of beaver activity or use of the area by other wildlife. Vegetation sketch maps of each segment were drawn on a base map prepared by Cohan to generally show where plants, downed logs, mid-channel bars, rocks, etc. occurred within the channel (Harner 6/4 at 89-90).

RESULTS AND DISCUSSION

General Discussion of Field Procedures

Location of Cross-Sections

Schumm stated that "statistics was invented to eliminate bias," where he defined bias as the tendency to inadvertently collect data favorable to the scientist's ideas. In his opinion, the State's team followed a scientific approach by considering a variety of explanations and eliminating those considered inadequate. He believed the Forest Service was following a "ruling hypothesis" that any change at the diversion sites was due to the diversion alone, and this could have caused them to unintentionally ignore negative data. He believed the Forest Service was looking for certain criteria which were not necessarily representative of channel conditions when they sited their above/below cross-sections (3/22 at 20-32). Harvey said, "if you have to look for adjustable reaches, you haven't got an adjustable channel" (4/3 at 710-714).

The Forest Service often only had one cross-section above and below the diversions, which the opposition deemed inadequate. In comparison, the State surveyed 20 sections placed at uniform intervals so they could run a statistical analysis on the data.

Cross-Section Measurements

There was some argument over whether the Forest Service's method of taking measurements at set intervals across cross-sections was better or worse than SLA's method of taking breakpoint measurements. Mussetter said the State's surveys were intended to represent the general cross-section shape, and they had used a flow resistance factor to represent roughness. He said the Forest Service was actually surveying across the bed materials (6/11 at 74-81; 6/12 at 60-62).

Slope

Mussetter said it was his opinion that the gradients listed by the U.S. were too flat because in many cases the Forest Service crews measured gradients in short reaches which were flatter than the average for the stream in that area. The average distance over which the U.S. measured slope was about 107 feet, and the longest distance 300 feet—compared to SLA's distances of 300-1300 feet. In Dunne and Leopold's book, they had advocated measuring slope over at least 30 channel widths, which would give about 150-600 feet for the quantification points.

Dunne and Leopold had also recommended running profiles of the streambed, water surface, top of bank and top of terraces, but the U.S. had not done this. Silvey said the reaches surveyed by the U.S. covered 3 pool-riffle cycles or about 15-20 channel widths. He believed these measurements were adequate for representing the gradient. He also noted that Dunne and Leopold's book said that experienced persons could reduce work to just a profile of the water surface (Mussetter 6/11 at 140-148, 151-165; Silvey 2/1 at 6-11).

Fluvial Sites

The "fluvial process study site data book" (Exhibit [A-604]) summarized information collected at the U.S. sites (2/9 at 129-130).

Discharge

Results of the field discharge measurements indicated that 1989 was a relatively dry year. Only one site had flows approaching bankfull flow, with most having peak discharges of about 30-40% of bankfull (Rosgen 2/8 at 98-100; 2/9 at 23-24). Therefore the flow and sediment data did not represent average streamflow conditions (Walch 6/21 at 27-32). Figure 7 shows a hydrograph for one site and a histogram of 1989 and bankfull values.

Painted Rock Studies

Even though bankfull discharge was generally not reached during the field season, 66% of the total number of painted rocks (507 out of 769) moved, including some of D_{84} size. Leopold mentioned that recent studies had indicated larger rocks such as the D_{84} actually moved at lower stresses than was previously thought because the large rocks stuck up into the stream and were exposed to more force from the flowing water than smaller particles on the bed hidden behind other rocks.

He said one disadvantage of this kind of study was the possibility of bias in placing rocks by hand; i.e. by placing them where they would be more or less easily moved. To avoid bias, a large number were placed to even out errors. Some rocks moved more than once, indicating they also moved from places where they had been previously deposited by the stream. Generally, the larger the discharge, the larger the percentage of rocks that moved.

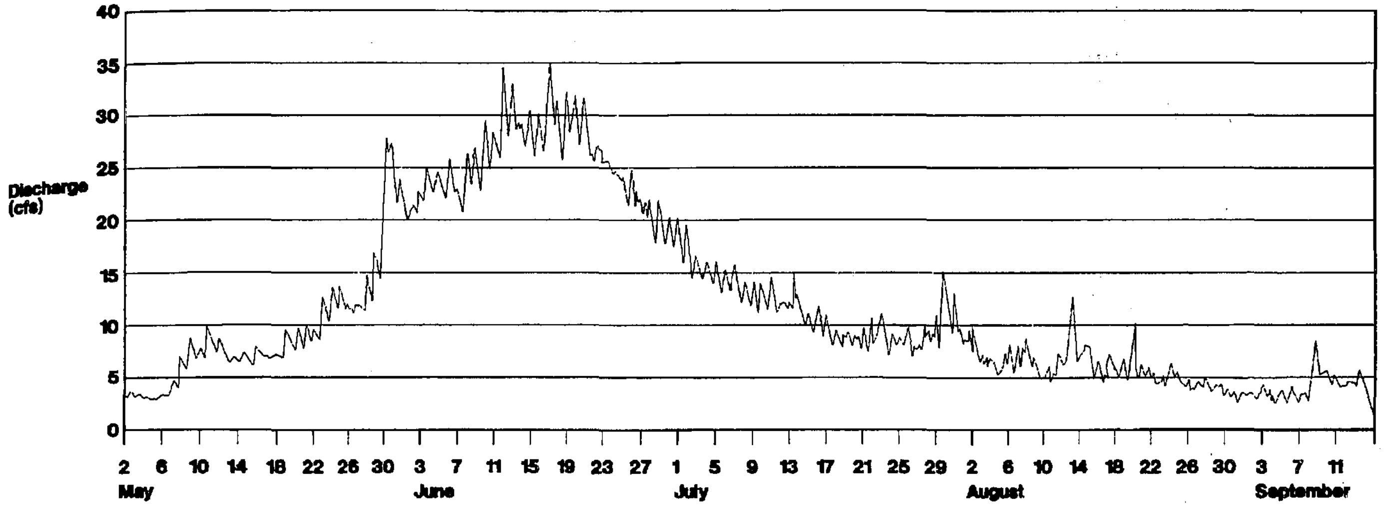
Leopold concluded from the painted rock studies that the material making up the bed moved even at discharges less than bankfull (Leopold 1/24 at 125-132).

The opposition attacked Leopold's conclusion from the painted rock studies. They said the results were unrealistic because the rocks were hand-placed on top of the streambed rather than flow-placed in a position of relative stability. Mussetter (6/25 at 26-27) said they should have been placed within the streambed. It was Schumm's opinion that the rocks simply bounced across the surface of the streambed which was not mobile. He said if the streambeds were mobile, large numbers of the painted rocks would have been buried. He also believed the studies were carried out over too short a period of time (Schumm 3/22 at 33-34).

Leopold responded to the criticism by saying, "there are always better ways to design experiments," which may not be possible due to restrictions in time, money and personnel. The rock movements were "natural" in the sense that they were moved by the flowing water. He also said that

Existing Conditions

Hydrograph, Little Beaver Creek, 1989



Comparison of Field Measurements to Bankfull Discharge

Fluvial Study Sites, 1989

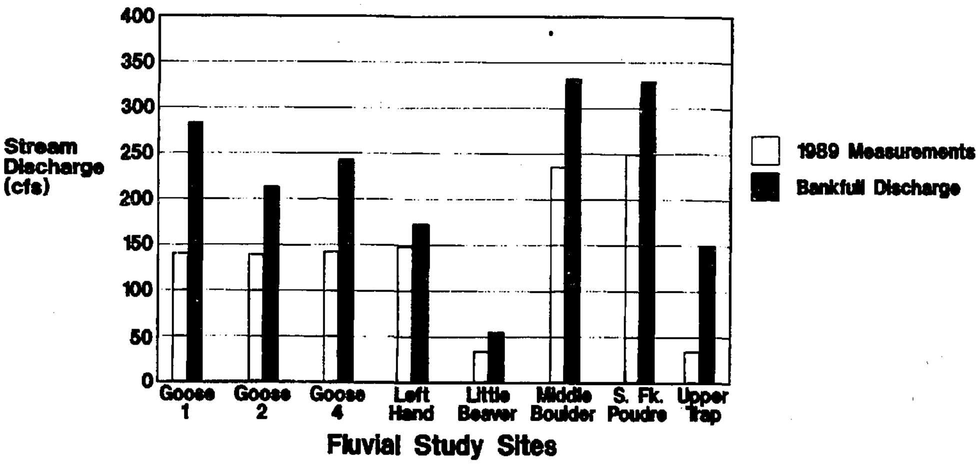


Figure 7.—1989 flow conditions at U.S. fluvial study sites. From Exhibit [A-713 and 714].

the subsurface materials didn't contain as many of the coarser particles, so as a general rule, the coarse bed materials were not likely to become buried (Leopold 1/25 at 48-49, 133-136).

Bank Erosion Studies

Rosgen presented examples from his work in Yellowstone as well as from the WD1 fluvial study sites. He showed pictures and cross-sections of four conditions: low erodibility/low stress; stable bank/high stress; high erodibility/low stress; and high erodibility/high stress. Actual bank erosion rates correlated well with the ratings. About 0.02-0.06 feet per year of erosion could be expected for a low erodibility/low stress site. For high erodibility/high stress, it increased to about 1.0-1.5 feet per year. The highest value measured was about 3 feet per year.

Rosgen pointed out that the results from the WD1 sites agreed well with his studies in Yellowstone, saying, "state boundaries don't seem to control these things. We are looking at physical processes" (2/9 at 88-92, 111-113, 120-124).

Sediment Transport

Mussetter compared the bedload data collected by SLA to that collected at the U.S. fluvial sites and found that the measurements were very consistent (6/20 at 82-83). Richardson said his team's data compared favorably with SLA's data (7/25 at 90-94).

Both sides presented the results of several analyses using the streambed particle size data and sediment measurements. These results are given in Section 6.

Comparison of Fluvial Sites and Quantification Points

The opposition brought out a number of dissimilarities between the U.S. fluvial process sites and the quantification points. They also attempted to demonstrate that the SLA sites were representative of WD1 streams. Their arguments are summarized as follows (Mussetter 6/11 at 137-141, 165-173; 6/20 at 44-50; Rosgen 2/12 at 44-46; Trout 1/25 at 114; Leaf 8/1 at 81):

- Drainage areas: approximately 70% of the quantification points had drainage areas less than 10 square miles. Very few had areas over 32 square miles. Drainage areas for the fluvial process sites were larger than about 80% of the quantification point areas, with one exception (Upper Trap Creek with a drainage area of 3.5 square miles). Drainage areas for the SLA sites ranged from 2-32 square miles, with one site having an area of 100 square miles.
- Channel slope: the fluvial sites had gradients less than about 3.5%, except for Upper Trap Creek which was steeper than 4%. For the 48 SLA sites, channel gradients ranged from ½% to over 10%, as measured in the field. This covered the range of gradients at the WD1 quantification points, with the exception of a few very flat streams with gradients less than ½%.
- Bankfull channel width: Even including the Upper Trap Creek site, the fluvial sites were wider than about 95% of the quantification points, for which the median width was only 9.5 feet. Bankfull widths at the fluvial sites ranged from 23 feet at Little Beaver Creek, and 23 feet to 53 feet at the South Fork of the Poudre. A little over 80% of the quantification points had widths of 17 feet or less. The smallest cross-sectional area at the fluvial sites was 25 square feet at Little Beaver Creek, and it was larger than about 90% of the quantification points. The largest was 74 square feet.
- Bed materials: Upper Trap Creek was the only site which approached a step-pool morphology. Most of the sites were on mobile gravel bed streams.

Mussetter found that a large number of quantification points had fine bed material. Many of these sites were ephemeral streams, several in the Pike National Forest.

About 54% of the SLA sites had cobble-sized D_{50} particles, and about a third were very coarse gravel. Mussetter concluded that the range of bed material sizes at the SLA sites were generally representative of the sizes found in snowmelt-dominated perennial streams in the national forests.

Walch pointed out that two fluvial process points had been left off the comparisons: Lower Trap Creek and Poudre Pass Creek (6/20 at 51).

In general, the fluvial sites were situated on flatter, larger streams with larger drainage areas than the quantification points. The fluvial sites tended to be on larger streams because that was where the USGS gaging stations were typically located. Rosgen (2/12 at 44-46) said the processes studied were still applicable even though the streams were larger.

SLA had also summarized the characteristics of streams discussed in the Chapter 30 references. Virtually all of those streams had drainage areas *greater* than 32 square miles. A vast majority had gradients less than 1%, with most less than ½%, and they had bed materials of sand and gravel. These were plains-type sand-bed streams which were not the same as ephemeral streams with fine-grained bed materials in the national forests, and were very different from the steep bouldery cascades which were typical of WD1 headwater streams.

Mussetter said that as the channels increased in size, they were more likely to be adjustable-type streams and less affected by obstructions than the more variable and stable mountain streams. He believed it was the U.S.'s intent to show that the streams were adjusted to the frequently occurring flows up to and including bankfull, and had supported this hypothesis by showing that sediment was moving in the stream, that bank erosion was occurring, and that they had caught isolated painted rocks representative of the coarse portion of the bed material sizes. Mussetter disagreed with the conclusions drawn from these observations, and believed the conclusions were even less likely to apply to the bulk of the quantification points. In his opinion, most of the quantification point streams were not mobile gravel bed streams (6/12 at 13-16, 20-23; 6/20 at 52-55).

DIVERSION STUDIES

U.S.'s Results

Physical Data

Out of a total of 21 sets of comparisons between paired above/below cross-sections:

- 3 showed an <u>increase or little change</u> in the cross-sectional area below a diversion. One of these diversions had not been in existence for very many years and had provisions for bypass flows for downstream water rights and for minimum instream flows.
- 18 showed a <u>decrease</u> in the downstream "new bankfull" cross-sectional area.

An example given for Lost Man Creek near Leadville indicated a 66.3% reduction in cross-sectional area downstream (Silvey 1/31 at 60-61, 72-74, 77). Other examples are discussed below.

Fraser River

Rosgen (2/13 at 80-83) described the effects of a diversion on the Fraser River. Dewatering the channel had led to vegetation encroachment downstream of the diversion. Sediment had been flushed downstream from a sediment pond behind the diversion, leading to clogging of the channel. As a result, when high flows occurred, they "took off" and downcut a new avulsion channel at a meander bend where the stream had aggraded and widened. Ventura, attorney for Denver, added that the Fraser River was a high sediment producer due to the presence of glacial tills, highly erodible soils and the presence of U.S. Highway 40 which was sanded in winter. She implied that the avulsion could therefore be the result of other factors than the diversion.

Three-Quarter Mile Creek and Two and a Half Mile Creek

Andrews (2/15 at 56-57; 2/20 at 119) discussed results from these streams, where ditches diverted *all of the water and sediment*. Well-defined channels no longer existed downstream of those diversions. Andrews said even though the sediment load carried by the streams had been diverted, the channel could still be "obliterated" by sediment from hillslopes. Continual channel-forming flows were needed to construct and maintain the stream channels.

In general, Silvey observed that there was an "identifiable response in terms of channel change" below most of the diversions. It was his opinion that if all or most of the stream flow were diverted from National Forest streams, the channels below diversions would respond similarly to the sites studied, with a reduction in capacity to transmit water and sediment. If high flows were re-introduced into the smaller channels, they would re-adjust and erode in an attempt to regain their former capacities. Channel maintenance flows would help maintain a stream's capacity for transmitting a normal range of flows (Silvey 1/31 at 68, 71, 99-101).

Vegetation Data

Potter summarized results of the vegetation surveys results by "zone," as follows:

Feature	"Above" water's edge to bankfull level	"Below" water's edge to new bankfull	"Below" new bankfull to old bankfull
Average foliar cover	26%	24%	50%
% area covered by soil, silt or vegetation	46%	43%	80%
Amount of "exposed" channel	1.4 feet	1.7 feet	6.3 feet

Figures for the "above" zone between bankfull and the water's edge and the "below" zone between new bankfull and the water's edge were similar, but the amount of vegetation in the "below" zone between new and old bankfull levels was higher. The results therefore indicated an increased amount of channel bed susceptible to invasion by vegetation downstream of diversions.

Potter pointed out that the quadrat and line transect techniques sometimes didn't agree. In the above table, the first two lines were based on quadrat data. He said that the line transect was more precise, but the quadrat sampling may have been more representative because it covered more area (1/26 at 83-4).

For the data on total foliar cover of vegetation less than 3′ tall, only 1 out of the 22 comparative sets of plots showed a decrease in cover below diversions; the rest showed the same or increased amounts below diversions. There was not a "remarkable difference" between the average number of woody stems 3′ tall above and below (Potter 1/26 at 81-87).

Potter also made some general observations during his studies. It was common below diversions to see sediments with higher amounts of fine particles and decumbant stems of willows which had become rooted within the "old bankfull" line. He also gave the example of Three-Quarter Mile Creek where essentially all of the flow had been diverted for a century and the stream channel had become a "swale" with vegetation like that of the surrounding forest (Potter 1/26 at 74, 76-80).

Andrews (2/20 at 56) had made the observation from upstream and downstream photographs that there was a lot more large woody debris lying in the downstream channels. Jacoby (1/29 at 138-142) had also observed that there were more debris dams below diversions. He believed this was because there were more trees in the downstream channels which could act as barriers to slow water flows and trap debris. The relative proportions were not formally evaluated.

The Opposition's Results

Harvey presented a detailed summary of the results for each diversion site (4/3 at 771 to 4/4 at 889). He ran 2-tailed t-tests on the means of the width and depth measurements taken upstream and downstream of the diversion to see if there were significant differences. In total, there were 13 channels, 14 ditches and 15 comparisons made, with results as follows (4/3 at 770, 774; 4/4 at 899-902; 4/11 at 22):

- There was no significant difference in either width or depth for 6 out of the 15 comparisons
- There was no significant difference in width for 9 out of 15
- There was no significant difference in depth for 9 out of 15
- Only in 3 out of 15 cases was there a significant difference in both width and depth
- At one site, the channel was actually wider downstream

There were only three sites where Harvey considered the upstream and downstream geomorphic settings to be similar, and these showed no statistical differences in width or depth. For the channels where there was a difference, Harvey believed that the geologic/geomorphic settings were not equivalent upstream and downstream. Harvey and Cohan gave numerous examples to support this conclusion. Four examples are given as follows (Cohan 3/27 at 137-159; Harvey 4/3 at 771-780, 797-802; 4/4 at 843-846, 849-865; Leaf 8/1 at 98-108):

- Lost Man Creek: This diversion was actually a reservoir and was 55 years old. Upstream, the stream had a relatively low gradient, but downstream it steepened and entered a bedrock gorge jammed with coarse moraine material. The State found statistical differences in both width and depth upstream vs. downstream, which Harvey attributed to geologic differences.
- Rapid Creek: This diversion was about 88 years old. The channel had a step-pool morphology upstream with large boulders. Downstream, the valley widened out with a coarse-grained debris fan—a "losing reach." The average upstream slope was 41% and the downstream slope 26%. The State found a significant decrease in channel size downstream; again, Harvey didn't think the upstream and downstream settings were comparable.
- Fraser River: The channel was significantly wider and deeper upstream, where it was in a meadow with fine-grained sediments and there was a backwater effect from the dam. The downstream section was affected by sediment from sanding of the adjacent highway in winter and from flushing of sand-sized sediment downstream from the diversion. The effects of this sediment extended downstream for about ¼ mile.
- Jefferson Creek: This diversion was 116 years old. Beaver activity was evident upstream, whereas downstream the channel was incised into an outwashed terrace within a forest. Widths showed a significant difference but depths did not. Harvey attributed the differences to geology.

Harvey concluded that the channels were extremely variable and reflected their geologic-geomorphic settings. He had not observed any indications of channel stability such as increased bank erosion, increased sedimentation and possible flooding problems even downstream of 100-year old diversions. He also pointed out that even where there was a decrease in width and/or depth downstream, it did not necessarily mean channel capacity was reduced because roughness and slope also entered into the equation. Opposition experts concluded that there were no changes in the channels below diversions, including reduced channel capacity, which could specifically be attributed to the presence of the diversion (Harvey

4/4 at 899-902, 913; 4/11 at 22; Leaf 8/1 at 98-108; Schumm 3/22 at 17-18; 3/27 at 26).

Walch pointed out that at several of the sites where Harvey had noted no significant change in width and depth, the diversions had bypass flows. Harvey had not studied bypass flows; only the morphologic data. However, he countered by saying if the bypass flows were maintaining those channels, then the U.S. wouldn't have measured a "new" bankfull level downstream (9/18 at 109-111). Of all the diversion sites, there were 5 where the channel had been totally dewatered and the State had not found a reduction in channel size downstream (Harvey 9/18 at 121-123).

Walch brought out that the State had dropped a number of cross-sections from their statistical analysis because they were affected by channel work, etc. Intervals between cross-sections were also inconsistent in places (4/4 at 918-919; 4/10 at 96-99, 114-132). He also asked Harvey why he had used a straight reach for computing the interval between cross-sections, implying that it may have been less variable and more likely to be in an adjustable section. Harvey said a straight reach was just used to calculate a sampling interval, because adjustable channels typically had a repetition of pattern "somewhere on the order of 5 to 7 times the width of the channel;" 5 was also easy to multiply (4/10 at 96-99)[3].

Walch said the State's cross-section locations could have fallen where there was a large boulder or tree trunk, and they therefore couldn't address the question of whether the channel would adjust to a reduction in flow. Schumm retorted that the State's data would certainly show that the channel would not adjust, and said the Forest Service's cross-sections were located "with a great deal of subjectivity" because they were trying to identify reaches which they thought were adjustable rather than average or typical reaches (3/26 at 126-129, 141, 147).

Walch also submitted maps and longitudinal profiles of the Fraser River diversion site prepared by the Forest Service using a high precision laser surveying instrument. His object was to show that the State's measurements using a compass and inclinometer were imprecise and not of sufficient scientific quality to be admitted into evidence. The precision maps showed considerable disagreement with the State's in terms of channel width, channel location, channel length and the general plan form of the channel. The Forest Service's maps also showed avulsions and a filled-in channel reach which indicated adjustment (3/29 at 358-365). The State eventually dropped all of its slope data and exhibits based on it.

Vegetation Data

Species of woody plants found growing along the stream channels included: honeysuckle, Ribes, subalpine fir, lodgepole pine, aspen, spruce, and willows. Harner discussed the locations within a channel where woody plants were commonly found; e.g. small groups of willows were found growing behind logs or rocks in areas sheltered from the flow, along banks or on mid-channel bars, and around and on top of beaver dams (6/5 at 29-37).

The vegetation data were summarized to obtain:

- woody plant basal density (stems per 100 square feet),
- total basal area (This was calculated in two ways: "worst" and "median"; i.e. for an A-class plant in the 0- ½" size range, the median diameter would be ¼" and the "worst" would be ½", the maximum size. Area was calculated as the area of a circle, in in^2),
- percent of woody plant basal cover (as a % of the total area in a channel segment).

Percentages were used to "normalize the data" in order to make comparisons between segments, between streams, and between upstream and downstream reaches. At Three Quarter Mile Creek, there was less than 1/100th of a percent of woody plant material in the channel both above and below the diversion (Harner 6/5 at 44-55).

In comparing percent woody plant basal cover upstream and downstream, 11 out of 14 sites showed an increase below the diversion. Other sites showed either no change or a decrease downstream. Harner said the downstream increases were "very minimal"; in fact, the percent cover figures were very small at under ½%. Therefore even if vegetation cover increased below a diversion, the amount influencing water flow would represent an insignificant percentage of the channel area, according to the State's data (6/5/90 at 59-60, 76-77).

Harner agreed that 11 out of 14 wouldn't be an expected result by chance, although he said the difference in vegetation could be due to other factors than just the diversion, e.g. slope or geology. He said vegetation was commonly located in protected areas near logs; therefore an increase in

[3] **Author's note:** *But if it is assumed that streams have a certain periodicity in their morphologies (i.e. pool-riffle or pool-step sequences), then by using a uniform interval of 5 x topwidth, the State was potentially only measuring in pools or only in riffles—therefore their "samples" were not random and not statistically representative.*

vegetation downstream of a diversion might be related to the number of logs falling into the stream.

Harner said the Jefferson Creek site had a forest community upstream and a willow/meadow community downstream, indicating that the ecological conditions were not comparable (Harner 6/4 at 81; 6/5 at 71-74; 6/6 at 172-173; 6/7 at 5-7). Potter (10/4 at 8-17) agreed that if he had selected the sites, he might not have included Jefferson Creek from an ecological viewpoint. Dougherty mentioned that the downstream section was on private land which appeared to have been intensively grazed in the past (9/18 at 159-161).

Harner also defended the information obtained by sampling as comparable to that obtained by total enumeration. For the sites where sampling was used, he said the percent basal area cover above and below the diversions were comparable, and gave these figures (6/7 at 31-32):

- Lost Man: 0.01% above, 0.02% below
- North Lone Pine: 0.10% above, 0.18% below
- Rapid Creek: 0.01% above, 0.03% below[4]

Graphs were prepared to illustrate the variability in the basal area data from one segment to another. Harner said because of the variability, the limited number of cross-sections measured by the Forest Service were inadequate (6/5 at 49-50, 56-58).

Potter (10/3PM at 55-69, 75) later presented a statistical analysis of Harner's data. The average stem density increased from 2 stems/100 ft^2 above diversions to 7 stems/100 ft^2 below. Using a Mann-Whitney non-parametric test, Potter showed that 7 out of 14 sites had a significant (at .05 level) increase in woody plant density downstream.

At Three Quarter Mile Creek, the water had been totally diverted for at least 100 years (Harner 6/5 at 68). The judge made the comment that there was a "heck of a lot more vegetation below the diversion than above it" (6/5 at 44-49). Zane pointed out that even though the basal areas were similar upstream and downstream, the numbers represented different conditions. The number of trees increased from 4 above the diversion to 511 below. Potter used the analogy of a fish net or bars on a jail cell to make the point that 64 stems of ½" diameter would have different debris and sediment-trapping capability than 4 of 1" diameter—even though they had the same basal area.

The 4 larger trees above the diversion were also located at the edge of the channel, but the majority of the stems in the downstream reach were located inside the channel banks. Harner agreed that the 500-odd plants downstream might have a greater impact than the 4 trees rooted on the banks upstream. He also admitted that the large number of plants downstream could have been due to the fact that all the water had been diverted from the channel over 100 years: "over the course of 100 years, you are seeing some plants established there" (Harner 6/7 at 17-25, 30; Potter 10/3PM at 78-81).

Harner concluded that (6/5 at 109, 113):

- Vegetation grew within the channels both above and below diversions. It grew on suitable substrate free of disturbancem, i.e. in locations protected from water flow.
- There was so much variability in the stream channels that it would be almost impossible to isolate a group of plants and say they were attributable to the diversion.

Mussetter remarked that the amount of woody vegetation growing within the diverted channels was so small that it would not have an adverse impact on channel capacity. In his opinion, fine sediment trapped by herbaceous or mossy vegetation could actually reduce flow resistance and create a cohesive deposit which was difficult to erode (6/19 at 108-115).

Aerial Photography Interpretation

Dougherty, a witness for Denver, had reviewed aerial and on-the-ground photography taken over periods of time in order to assess changes above and below diversions. From the photography, he had measured "potentially suitable substrate" which was the area within the channel lacking in vegetation, but supportive of it, e.g. on bars and banks. He said the "inner berm" mentioned in Chapter 30 had the greatest potential for encroachment. His theory was that if vegetation encroachment did occur as a result of a diversion, it would occur in these areas (9/18 at 136-139, 152-154). The areas were smaller than the areas covered by vegetation. Dougherty therefore believed they would be more sensitive for showing changes (9/18 at 154-159).

Dougherty collected photography for sites where the diversion was about 50 years old, and before/after photography was available. He focused on diversion sites in meadow areas because these streams had more bars and therefore a higher potential for encroachment, and because the streams beneath forest cover couldn't be seen in aerial photos. He looked for sites with comparable environmental settings upstream and downstream (9/18 at 154-159).

[4] **Author's note:** *The numbers are very small due to the method of computing basal area as a percent of the whole channel segment area. Note that the last comparison actually represents a 300% change from upstream to downstream.*

Dougherty concluded from his studies that (9/18 at 176-180; 9/19 at 44-46, 59-61, 83-89):

- There was "no clear-cut trend" towards vegetation colonization below the diversions. Vegetation moved out onto the bare areas and back again both before and after diversion, and both upstream and downstream of diversions. Vegetation retreat could be caused by inundation by beaver ponds or ponds created by log jams.
- The streams were "very noisy systems" because of effects from beaver jams, log jams, debris flows, avalanches, ice jams, etc.
- Without a historical perspective, there was no way to know what part of the cycle the 1989-1990 situation represented.
- If vegetation encroachment were occurring, it would be obvious as a system-wide "pervasive problem," and Dougherty hadn't seen that kind of process in the mountain streams. Cross-sections wouldn't be needed to analyze encroachment if it were occurring because it would be obvious from observations.
- Dougherty had also analyzed the Forest Service's data, and believed there were a number of sites which didn't have comparable environmental settings upstream and downstream, e.g. Jefferson Creek. He said there was so much "noise" that a few cross-sections above and below a diversion which weren't randomly placed didn't give a valid comparison. He said, "you can prove just about anything you want to by selecting certain stream segments."
- It was Dougherty's opinion that the base flows claimed by the Forest Service for preventing vegetation encroachment were less than what was necessary to flood the "inner berm" which was most susceptible to vegetation encroachment. Therefore it wouldn't do the job. Based on his observations at the diversion sites, he had not seen vegetation encroachment even where all of the flows were removed.

In cross-examination, Zane brought out that Dougherty didn't have information on the hydrology of the sites (9/19 at 100-105, 126-137). Potter later did additional work on the U.S. and State's data to show that suitable plant growth medium (SPGM) increased downstream of the diversions at 9 out of 14 sites (10/3PM at 88; 10/4 at 5-7). He criticized Dougherty's studies in which he had used meadow areas which weren't representative and had mapped bare bars rather than vegetation as a measure of encroachment. The amount of bare bar area exposed could be affected by water level. Potter defended his own method of measuring vegetation from the water's edge, implying that the vegetation cover was somewhat "fixed" whereas the bare areas would shrink or grow depending on water level (10/4 at 42-48, 52-53). He also said North Lone Pine Creek below Mitchell Ditch was an "obvious" example of vegetation encroachment. It was completely overgrown and was more like a mountain valley (10/3PM at 77).

Tree Ring Studies

Jacoby, an expert for the U.S., used tree ring analysis for two purposes:

1. to determine the ages of "leaning" trees which were indicators of channel adjustment, and
2. to determine the ages of trees which had encroached into the stream channel below diversions.

His purpose was not to develop statistically significant results, but to demonstrate the processes taking place (1/29 at 79).

The procedure used for tree ring analysis consisted of boring into a tree past its center with a Swedish increment bore. A core was withdrawn from the instrument and placed in a protective straw for later analysis. Information about the tree location, compass direction of the core, etc. was written on the outside. The sampling was considered non-destructive like taking a blood sample, and the bore hole healed within 1 or 2 seasons. In the laboratory, core samples were mounted and sanded and the rings measured to .01 mm or finer scale using a "measuring machine" developed by Jacoby (commercially available from Velmex Unislide), or with x-ray densitometry (Jacoby 1/29 at 7-12).

U.S.'s Leaning Tree Study

Undercutting of streambanks and erosion of root support caused trees growing along streams to tilt and eventually fall into the river. By analyzing tree rings, the date of "tilting" could be evaluated. When trees tilted, "reaction wood" was produced as a result of the tree attempting to again grow vertically towards the sunlight. In conifers, reaction wood primarily grew on the downhill side of trees and "pushed" the tree upwards. In broadleaf trees, it grew on the uphill side to "pull" the tree upwards, and was called tension wood. Jacoby said leaning trees were typically seen at the outside of bends where bank erosion tended to be the greatest (1/29 at 22-26, 28).

Jacoby (1/29 at 30) concluded from his research on leaning trees in WD1 streams that the streams were indeed eroding and adjusting their shape, and the rate of bank erosion was "on the order of a rate that should be considered in human planning."

Mogren, an opposition witness believed the trees weren't leaning because of streambank erosion. In his opinion, the leaning was due to the way seedlings grew roots into the bank but not out into the air, making the roots asymmetrical. A tree could also lean towards the stream because it was shaded on the other side by the "forest wall," which caused its crown to atrophy and die on that side, making the crown heavier on the stream side (6/6 at 75-80). Jacoby later showed pictures of trees leaning towards the stream which were next to an open forest, indicating it wasn't competition for light which caused them to lean (10/3 at 28-35).

U.S.'s Above/Below Diversion Study

For the "above/below" tree ring studies, older trees were sampled above and below diversions. Only trees within the bankfull channel were sampled, unless there were no trees in the channel—in which case outside trees were sampled. Cores were taken as low as possible to obtain the maximum age. Tree species, ages and locations were recorded. The tree ring count was later adjusted for growth which took place before the tree reached the coring height (Jacoby 1/29 at 40-1, 50-53, 81).

Jacoby showed photographs of younger cottonwoods growing on a bar below the "old bankfull" level downstream of a diversion. He said cottonwood seedlings were very sensitive to abrasion, but if they had a reduced flow period when they could take root, then they could develop into a woody plant which was resistant to flow. Older cottonwoods in the photograph were tilted, with scarring from high flows, showing that high flows did come through but that trees were resistant to them (Jacoby 1/29 at 34-9, 73, 138-142). Jacoby pointed out that lodgepole pines were not typically found in wet areas, because they required an aerated soil zone for at least ½ of the growing season. However, several lodgepole pines were found growing within the "old bankfull channel" below diversions and had ages which were younger than the diversion (1/29 at 55-76).

He gave an example from Lost Man Creek where the diversion dated back to 1935. No trees were found within the active channel above the diversion, whereas a number of trees were found within the "old bankfull channel" below the diversion which were younger than the diversion (1/29 at 59).

In 14 out of 15 above/below pairs, Jacoby found woody plants within the "old bankfull channel" below the diversion. The exception was at a site where diversion didn't start until 1985 (1/29 at 71). There was only one location where a woody plant was rooted within the active channel *above* a diversion, and Jacoby said it was growing in a protected location (1/29 at 103).

State's Tree Ring Studies

In 1989, Mogren went to all 13 of the U.S. diversion sites and collected cores from trees adjacent to the streams above bankfull level, both upstream and downstream (6/6 at 40). He measured the widths of 10 rings before and after the diversions had been put into service. These cores were first sanded, and then the rings were measured under a microscope with a steel ruler graduated in 1/100ths of an inch. He couldn't use all of the cores because he wasn't always able to obtain trees older than the diversion both upstream and downstream. Out of the 93 cores taken, only 26 were used. The dates of the 5 diversions for which cores were adequate ranged from 1883 to 1936 (6/6 at 59-62, 113-114).

Mogren's results indicated that in general, there was an increase in growth rate after the diversion both upstream and downstream, or no difference. On one creek, there was a decrease in growth rate after the diversion site both upstream and downstream (6/6 at 63-66).

Mogren studied the ages of trees adjacent to the Fraser River as an indication of how long the stream had been in its current location. A total of 90 cores were taken, 82 of which were within 2 feet of the stream (6/6 at 66-68). The trees were aged by counting the number of rings in the cores, then adjusting the total by the number of years required for the tree to grow from a seedling to DBH (4.5 feet), where the core was taken. Mogren relied on research done by the Forest Service which gave an additional factor of 9 years for lodgepole pine, and 20 years for spruce. Mogren pointed out that the trees along the streams were not all the same age, and believed they had the same age structure as trees in the adjacent forest. He demonstrated that all of the trees growing in close proximity to the stream below the Fraser River diversion pre-dated it, indicating they had not been disturbed by the diversion (6/6 at 69-75, 128-132).

Mogren also collected data on the locations and number of trees along the margins of channels at all diversion sites. He used a unit of measure called basal area per acre, where basal area was the cross-sectional area of the trees at DBH. Mogren used a "wedge prism," an optical instrument commonly used by foresters, to take these measurements (6/6 at 44-50, 102). For each segment, Mogren would stand on each bank and make a count of trees on the other side. A conversion built into the prism converted counts of trees to basal area per acre, which was summarized separately for right and left banks (6/6 at 51-53). Mogren said the prism had a ratio of 1:33, meaning that there was 2.75 feet of reach per inch of tree diameter, e.g. a 10-inch tree would be 27.5 feet away. If a tree was close enough to be counted, it constituted 10 square feet of basal area. Zane pointed out that it was standard practice to select this factor in accordance with the average tree diameter at the site, but Mogren hadn't done this (6/6 at 102-109).

Mogren's basal area data were summarized by measurements taken above and below the 13 diversions. He said that in most cases, the differences were minimal (6/6 at 53-55). He attributed some differences to the presence of a beaver swamp, and to fire and logging disturbances. At Lost Man Creek, there was really no forest cover either above or below the diversion.

From his studies, Mogren concluded that the diversions had not caused changes significant enough to be a disturbance to the forest immediately adjacent to the streams (6/6 at 56-57, 83-89).

The U.S. effectively negated Mogren's testimony. For example, Zane brought out in cross-examination that the trees Mogren sampled along the Fraser River were actually along an avulsion channel, not along the stream channel. The true channel was encroaching into a mature forest (6/6 at 128-132). Jacoby also reviewed the maps displayed during Harvey's testimony and found only three locations where trees were located on both sides of the stream, constraining it. At all other locations the trees were only on one side or out on the floodplain. Jacoby said, "the mere presence of a tree. . . does not indicate stability" (10/3AM at 23).

Zane also pointed out that some of Mogren's cores were taken from leaning trees, on the side where there would have been reaction wood and the growth rates would have been higher (6/6 at 92, 128-132, 136-137). Jacoby said at least two cores should have been taken from the leaning tree and the growth rates averaged to get a representative value (10/2PM at 78-80).

Jacoby evaluated Mogren's cores and said many were poorly prepared and the date of diversion was marked incorrectly on about 1/3 of them because he had missed faint or very narrow rings (10/2PM at 46-52). Another type of error was that Mogren did not standardize his measurements; i.e. the data from large trees and from trees with higher growth rates would dominate the data set. Standardization involved reducing the tree ring data into indices with a mean of 1 and a ring growth rate based on mean growth over some time period (10/2PM at 54-58). Trees typically had a sigmoidal growth curve because they grew slowly at first, then at an increased, perhaps linear rate, and then they grew more slowly as they reached maturity or the canopy closed. One method of removing the trend was to fit a curve to the growth trend (e.g. negative exponential). Jacoby estimated that about 1/3 of Mogren's cores showed a substantial growth trend, and his conclusion that the trees showed a decrease in growth after the diversion was really due to the fact that the trees were just growing more slowly due to age (10/2PM at 58-63, 74; 10/3 at 6, 11, 14).

Jacoby said that for simply aging a tree or determining a date of disturbance, multiple cores and standardization weren't needed. However, for comparing growth rates it was important. Jacoby said he personally wouldn't make any conclusions based on Mogren's numbers (10/3 at 12-14). He also said the State's use of location and age of the trees was not sufficient information to indicate channel stability (10/3 at 35-36). The Forest Service had used a stricter interpretation than the State to describe which trees were actually in the channel, because they had only sampled trees which were clearly within the U.S.-defined bankfull level. Jacoby was interested in the question of whether or not vegetation had germinated and continued growing within the channel. The State's interest was in showing whether the streams were adjustable or not and whether vegetation affected flows (6/7 at 14-15; 10/3 at 60-64).

At the site where the State had recorded the most trees growing within the upstream channel, Rolling Creek, Jacoby had gone back to identify the trees recorded on their maps. He found that many trees were growing on the streambanks and sloping into the stream because the banks were undercut. The State had recorded these; the Forest Service had not. He believed the State had recorded more trees within the channel both above and below diversions, and that the "noise" from this larger data set could "drown the signal of trees in the channel or not in the channel." He concluded that the Forest Service's study had been correct, and for Rolling Creek, it showed no trees in the upstream channel and over 80 downstream (10/3 at 14-23).

FIELD TRIPS MADE DURING THE TRIAL

Three field trips were taken during the trial to familiarize the judge with conditions in the national forest streams. Witnesses accompanying him on the trips included Leopold, Madole, Silvey, Potter and Andrews for the U.S., and Schumm, Leaf, Harvey, Mussetter and Harner for the opposition. Each side was allowed to choose particular sites to visit. The U.S. selected sites within Rocky Mountain National Park to illustrate general fluvial processes and the effects of glaciation. The State added the Fall River so they could discuss sediment transport (see Section 6). In addition, the U.S. chose to visit a diversion site on the Laramie River and the State chose quantification points downstream from the South St. Vrain diversion site (6/20 at 28-43). Sites were visited on July 13-14 and August 3, 1990.

General Comments

While looking at a meandering stream in Rocky Mountain National Park, Andrews (7/13 at 9-10) stressed the fact that although the stream contained large rocks which might be immovable for a decade or so, these hadn't constrained the channel width or inhibited development of a floodplain. Harvey pointed out that the stream chosen to illustrate this point had a larger drainage area than 96% of the quantification points. He also produced aerial photographs to show the stream hadn't moved in its course since 1938 (7/13 at 13-16). It was his opinion that this river only moved by avulsive-type processes about every 1000 years when meanders aggraded, and that this process wasn't the same as the adjustment of plains-type streams (7/13 at 38-39). At another site, he agreed with the U.S. experts that climate shifts during the Holocene had left terraces, but said the discharges causing the downcutting had nothing to do with today's hydrologic regime. The channels hadn't "been anywhere" since the terraces were formed (7/14 at 35-36, 56-57).

The opposition maintained that little sediment was transported into or through the streams because most runoff in the subalpine zone entered the stream through subsurface flow and because the streams were very stable. Harvey believed sediment transport rates were normally very low, and that sediment delivery in the mountain streams tended to be "catastrophically-driven" (7/13 at 48-49). Leopold argued that even a small quantity of material could amount to large volumes over geologic time. Andrews added that the channel maintenance flows were designed to "keep things right" in the long-term, not just the next decade or so (7/13 at 24). Leopold also pointed to a draw with an alluvial fan at its base which indicated that surface water and sediment could reach the streams (7/13 at 44-45). Andrews had observed one of the same streams during a rainstorm the week before and said it was very muddy then (7/13 at 57-58).

South St. Vrain Quantification Points

The downstream quantification point on the South St. Vrain (47A) had one of the largest drainage areas, and its bankfull width and cross-sectional area were the largest of all of the quantification sites. The bankfull claim was about 500 cfs for 4 days and a base flow of 4.5 cfs was claimed for 279 days. Discharge was about 100-150 cfs at the time of the field trip (7/13 at 77-78). The slope was 2.6%, the D_{84} 300 mm and the D_{50} 90 mm (7/13 at 67). Andrews had calculated that the streambed would be mobile at bankfull flow, but Mussetter pointed out the large "structural elements" which would not move and would slow the water and reduce shear stress on the streambed (7/13 at 79).

A diversion upstream took about 50% of the flow on average. It had been in existence for 130 years, but Mussetter said there were no adverse impacts at this site (7/13 at 80-82).

Potter pointed out cottonwood and willow trees which were tolerant of flooding and capable of moving into the stream if flows were reduced (7/13 at 73). Harner said the vegetation only occurred along the banks and in protected areas and wasn't moving into the channel (7/13 at 76-77). He also mentioned that the U.S. experts had not pointed out "new" and "old" bankfull levels at this site (7/14 at 25-26).

Leopold agreed with Mussetter that about half of the water was diverted—but this was exactly what the U.S. was asking for. U.S. witnesses had been testifying all along that 50% of the water could be removed and the channels would still be maintained (7/13 at 85-86). The U.S. claims were intended to prevent diverters from taking any more water from this channel (7/14 at 16). Andrews said the objectors wanted to "take every last drop out of this stream and leave nothing in it except during times of flood flows when their diversions can't handle it." He argued that the forests were set up to protect the watersheds in perpetuity (7/14 at 16-19).

The group traveled up the canyon to other quantification points closer to the diversion site. One site was an "A2" stream type with a slope of 9-10%. The diversion site was just upstream and normally this reach was dry (7/14 at 88-92). The U.S. claim hadn't taken the diversion into account, which had resulted in an excessively high duration for bankfull discharge (see Section 7). This stream was cascading through large boulders which Harvey did not believe would move at bankfull flow; in fact he had difficulty even defining bankfull level (7/14 at 93-96). The present flow of 20-25 cfs was fairly close to the U.S.'s 30.5 cfs bankfull claim. Andrews had calculated that the streambed would be mobile at 31 cfs, but Mussetter said it was obvious that it wouldn't be. Even with the long-term diversion upstream, there wasn't an accumulation of sediment in the channel (7/14 at 100-101).

Laramie River Diversion Site

The first stops were above the diversion, which dated back to about 1937 (8/3 at 55-56). This was also a fairly large river, with one point having a drainage area larger than 90-95% of the quantification points (8/3 at 8-10). Referring to a section of the stream on an alluvial fan, Schumm and Mussetter said it was characteristic of these channels to shift position. They were "avulsive in nature"; however the processes weren't the same as for meandering plains streams (8/3 at 2-3, 8-10). Andrews pointed to boulders which had been placed in an abandoned channel to block it off as an indication that the stream was actively eroding its banks and shifting course (8/3 at 2-3). The evidence of several old channels indicated that the stream was carrying a substantial sediment load (8/3 at 22-23). Mussetter said an old beaver dam had breached upstream, releasing deposited coarse material which was affecting the reach (8/3 at 29-31).

Potter referred to a side channel which only received flows periodically and was filled with grasses, sedges, willows, horsetails, aspen "clones" and willows. He made the point that a high water period every 10-20 years would not get rid of encroaching vegetation (8/3 at 11-20).

Below the diversion, the channel capacity was only 1/10 or less of the upstream capacity. The channel bed contained fine sediment and was constricted by vegetation and sediment deposits. Andrews said the occasional high flows entering this reach didn't maintain the channel because most of the flow occurred outside the bankfull channel (8/3 at 41-46). Andrews argued that the channel had adjusted to a smaller size due to accumulations of fine materials, and that this was the principal adjustment of concern by the U.S., not the movement of the large structural elements in the channel (8/3 at 47-49).

Schumm described the area as a "beaver swamp." He said there were actually many side channels which carried water, which was the explanation for a smaller channel at this location (8/3 at 60-65). Andrews argued that the multiple channels weren't all active—that there was only one primary upstream channel and one primary downstream channel which was smaller. The other channels were relics (8/3 at 69-71).

This site was important because the judge said in his final decision (p. 21) that it was really the only example he had seen where the flow might be impeded by sediment accumulation and vegetation encroachment. At this site, he believed it was "perfectly clear" that the downstream channel wouldn't hold all the flow. However, he said the fact that this was the <u>only</u> example he had seen might lend credence to Schumm's opinion (11/15 at 70-73; Decision at 21-22).

THE OPPOSITION'S CRITICISM OF THE U.S.'S DIVERSION STUDIES

- Schumm (3/22 at 17-18; 3/27 at 26) believed the Forest Service's data collection procedures at the diversion sites were "inadequate," "unprofessional," and the results were biased.
- <u>The diversions were located at strategic points, not randomly</u>. Simons discussed some of the factors considered when siting a diversion such as water supply, an elevation which allows gravity flow, a good foundation, and a flat upstream reach to allow some sediment to deposit out before the diversion. He said it was common to site diversions at "breakpoints" in slope, where it was flatter upstream and steeper downstream. This was often at a bedrock control. He had been to 8 of the diversion study sites, and said many were sited such that there was a significant change in grade from upstream to downstream (4/11 at 136-143; also Dougherty 9/19 at 50-59).
- The above/below comparisons were not valid because there were geologic and

geomorphic differences not attributable to the diversions. Ventura (1/26 at 107) pointed out that several above/below comparisons involved comparisons of different Rosgen stream types. For example, Jefferson Creek was classified as B2 above and C1 below. Sansone (2/1 at 41-43) demonstrated that slopes were very different; for example, at Rapid Creek, the "above" slope was 41% compared to the "below" slope of 26%.

- The use of "new" and "old" bankfull lines below diversions was questionable. The opposition believed the Forest Service had used features for identifying "new" and "old" levels which were depositional features locally controlled by boulder contractions, LWODs, washed out debris dams, etc. The State looked for the existing channel (Harvey 4/3 at 700-709; Angel 12/11 at 73-80; Mussetter 6/21 at 65-68).
- The Forest Service had not been consistent in locating cross-sections for above/below comparisons. In Harvey's opinion, the Forest Service had selected their cross-sections based on an assumption that a limited number of "equivalent" cross-sections upstream and downstream was sufficient. Harvey did not believe their assumptions were justified. They had located some meander cross-sections upstream of the apex of the meander and some in the downstream limb of the bend—these were not comparable locations. He also gave an example of a straight reach where the upstream bankfull width was much less than the downstream "old bankfull" width, but both should have represented the pre-diversion channel; the sections were therefore not comparable. He concluded that there was no basis for making an interpretation about the effects of diversions from the Forest Service's data because (4/3 at 699-709; 4/4 at 899):
  - they didn't use equivalent sampling locations,
  - the number of sections was too few to test for bias with statistics.
- The U.S. top width measurements obtained by the vegetation crews showed bias, and disagreed with measurements made independently at an earlier date by hydrology crews or with measurements made by the State. Harner gave one example where the hydrologists' "old bankfull" width was 6.6 feet and the vegetation crew's width was 8.9 feet. The extra width would have allowed extra quadrats to be added nearer to the banktops where Harner had observed most of the vegetation occurred. A comparison of the width measurements taken by the two, U.S. crews showed a considerable amount of scatter—greater than the 5% error expected from the difference between a taut tape and a slack tape (6/5 at 94-104, 111). Potter had even discarded some cross-sections because of a discrepancy between his measurements and those recorded by the hydrology crews (4/3 at 765-769; 4/4 at 827-836).

A comparison between the State's bankfull widths and those measured by the Forest Service's vegetation and hydrology crews showed good agreement above diversions. Below diversions, the Forest Service's "new bankfull" widths were much less than the State's measurements. The State's bankfull widths generally fell between the U.S.'s "old" and "new" widths. Cohan gave an example where the State had measured 12.2 feet below the diversion and the Forest Service's new bankfull width was 4.4 feet 3/27 at 128-36). Harner suggested that the U.S. crews had a "propensity" to measure a smaller bankfull width above the diversion than below. Because most of the vegetation grew along the edge of the bank, this propensity would tend to give higher percentages of vegetation cover downstream (6/5 at 99-106).

The State's experts brought out that the discrepancies between the U.S.'s vegetation transect lengths and bankfull widths ranged from 0 to 237.1%. The highest variation reported by Potter had been 34.8%; however the State also included sections which Potter had dropped from his analysis. Sansone argued that the taut tape method used by the hydrologists should have always given lengths equal to or shorter than the slack tape measurements, yet there were 12 out of 30 transects where the slack tape widths were less (10/4 at 36-39).

Harvey's interpretation was that everyone was measuring the same thing upstream of diversions, whereas downstream the U.S. researchers couldn't agree with each other and the U.S. and State measurements didn't agree. The State used a consistent definition of channel capacity both upstream and downstream (4/3 at 756-758).

- The U.S. vegetation crews had taken more transects below diversions than above. Potter had said this was done in order to focus on the process of encroachment (1/26 at 125-126).
- The Forest Service's quadrat method had the potential for allowing double-counting of

vegetation. Harner criticized the procedure of holding the quadrat over the ground rather than placing it on the ground surface. It was a "sloppy" technique which introduced parallax, causing the quadrats to be larger and adjacent quadrats to overlap (6/4 at 63-70; 6/5 at 111).

- Basal cover was a more accurate representation than canopy cover of the effect of vegetation on water flow. Harner believed canopy cover, measured by the U.S., overestimated the amount of vegetation in the channel influencing water flow (6/5 at 76-77). The U.S. had also measured canopy cover at 3' off the ground, which was well above bankfull level in many cases (6/5 at 9-14).

Zane defended the U.S.'s method of surveying canopy cover, saying that Harner had mischaracterized it. The U.S. vegetation crews had taken two quadrat measurements: 1) one near the ground, and 2) at 3' above the ground using an "open-ended" quadrat with no grid wires to estimate cover over 3' tall by projecting it to the quadrat. These plants were distinguished as either rooted in the channel or on the bank. These data were kept separate from the data for plants less than 3' tall (6/7 at 7-9).

- The U.S. vegetation surveys did not produce information on the percent of bankfull area filled with vegetation. This figure would better represent flow impedance (1/26 at 140).
- There were other potential causes of vegetation encroachment besides the diversion, such as beaver dams, road building and sanding of the highway near the Fraser River in winter (Ventura 1/26 at 114-117).
- Debris jams were fairly equally distributed above and below diversions. Harvey had not observed more debris jams downstream, as the Forest Service had alleged (4/4 at 898).
- The area between "new" and "old" bankfull levels downstream of diversions was still available for water to flow through it (Harvey 4/3 at 709).
- In conclusion, the U.S. hadn't presented any clear evidence that channels downstream of diversions were filled in with sediment and vegetation. Angel finished off her cross-examination of Andrews by saying, "in all the material that you studied and that you produced, you can't show me even one documented instance of a particular flood impact being increased due to a diversion in the National Forest in Water Division 1" (2/20 at 83).

U.S. REBUTTAL ON DIVERSION STUDIES

Upstream/Downstream Differences

Andrews defended the differences in bankfull width measured by the vegetation and hydrology crews. He believed the actual absolute widths were not as important as the fact that they changed from upstream to downstream of a diversion (12/11 at 73-80). Both the U.S. and the State had observed that the channels downstream of the diversions were commonly smaller. However, the State had attributed this decrease to differences in slope, particle size, vegetation, etc. Andrews said these factors could affect width and depth but not the bankfull channel capacity, which was defined by water discharge. He said the responses downstream from diversions represented a "complete continuum" from almost no change to situations where there was virtually no channel downstream. In his opinion, this was a result of the relative amounts of water being diverted (12/10 at 147-150).

Andrews gave these additional examples to support the U.S.'s position (12/10 at 150-156):

- Fraser River: The channel downstream of the diversion was "partially maintained" because of bypass flows.
- Beaver Creek: There were actually two diversions at this site and the second one took almost all the water. Downstream from it, a channel couldn't be seen because it had filled in with sediment and vegetation.
- South St. Vrain: Most of the water was diverted and the downstream bankfull capacity was about 10 times smaller.

Madole also disagreed with the State's depiction of geology at the diversion sites and their statement that most of the material bounding the streams was delivered there "by processes unrelated to the current hydrologic regimen," i.e. by glaciation and mass wasting. He found that the State had made errors in their descriptions of geology and geomorphology at 5 of 11 sites visited by Madole. The judge would not allow Madole to testify on these errors because the opposers had not been given prior notice that he would cover this (10/4 at 105-118).

Madole also addressed the statement of Schumm's about the Laramie River. Schumm had suggested that the downstream channel was divided into several channels and they were only looking at one, whereas they were looking at an undivided channel above. Schumm had also mentioned beaver activity as a cause. Madole returned to the site in September, 1990 to look for the remnant channels which Schumm had diagrammed. He concluded that beavers were not the cause of the difference in channel sizes. He also found that the channel below the diversion was an extension of the upstream channel. The other small channels were prehistoric channels and did not presently carry water. They had filled in with sediment and vegetation (10/4/90 at 118-139). Silvey also showed aerial photographs taken in 1937, 1973 and 1989 to demonstrate that the downstream channel was gradually being covered by vegetation. A comparison of cross-sections above and below the diversion showed a reduction in channel capacity downstream. He concluded that the channel was partially maintained by intermittent bypass flows (11/14 at 161-172; 11/19 at 28-35).

Potter defended the U.S. vegetation crew's use of a slack tape. He said the hydrology and vegetation widths were different types of measurements and it wasn't valid to compare them. His own calculations showed an average variation of 14.5%. The actual vegetation lengths were within old bankfull lines and did not include extra banktop vegetation. He also submitted an exhibit to show that removal of the 8 "questionable" paired data sets did not make a significant change in the results (10/3PM at 10-36, 48-49; 10/4 at 17-36, 53-54).

U.S.'s Criticisms of the State's Diversion Studies:

Plan View Maps

Gabbert reviewed Cohan's sketch maps of the diversion sites by comparing the State's field notes to the information shown on the maps. He found a total of 546 "errors and omissions" such as missing overbank channels, logs in the channel which should have been outside, missing cross-sections, etc. At one site, he had personally observed channels "all over the place," but there was no indication on the State's maps that the channel had ever moved (10/1 at 24-31, 35-42, 63-70).

Walch had conducted a 1½ day *voir dire* examination of Cohan's exhibits. In all, he lined up some 60-70 feet of corrected maps around the courtroom prepared by Gabbert. Walch appeared determined to question Cohan about every one of the errors and omissions (3/27 at 159 to 3/29 at 377). She repeatedly defended them as just being schematic drawings and said she had used a certain amount of "artistic license," to which the judge added, "just like the state capitol on a map usually is a circle with a star, but if you look at the capitol it certainly doesn't look like that" (3/28 at 228-231).

In his inquiry, Walch posed a question about how Cohan had measured bankfull width across the tops of islands in the center of the stream. Cohan said that for some locations, the "islands" were gravel bars which were submerged at bankfull flow; other locations had "split flow" at bankfull, and width was only measured on either side of the "split" (3/28 at 291-297).

By "nitpicking" over the differences between what was on Cohan's maps and what was recorded in her field notes, Walch was attempting to demonstrate that she chose to selectively include features which indicated a lack of channel adjustability; e.g. bedrock and boulders—and exclude features such as gravel bars and abandoned channels which were evidence of sediment transport and channel adjustment (3/28 at 278-291).

The State's attorneys later pointed out that Gabbert had made mistakes in his analysis; e.g. labeling a few pages as "above diversion" instead of below, and listing features as missing which were really included (Sansone 10/1 at 32-33, 173-188). The line drawn down the channels in the State's maps was just a center line, not the thalweg line; however Gabbert believed the line should have connected the deepest points and considered this an error (10/2AM at 25-32). Cohan noted that many of the "errors" were really just applications of common sense in interpreting the field notes (3/29 at 390-393). Mussetter (6/19 at 80-89) had also gone through the errors listed by the U.S. and had found only a "handful" which he considered errors; the rest were minor and wouldn't have an effect on overall conclusions. He said the intent of Cohan's maps was only to show the general characteristics, not every piece of bed material.

The judge supported Cohan by saying it wasn't unusual for exhibits to be prepared to support one side. He believed the maps were acceptable as representations of what the State's researchers had observed (3/28 at 303-305, 334-335, 395; 3/29 at 377-385).

Cross-Section Measurements

Gabbert criticized the State's procedure of just measuring maximum depth because it didn't tell anything about the rest of the cross-section, e.g. if it was actually filled in with vegetation or gravel bars (10/1 at 43-45). Using the State's field notes, Gabbert drew up cross-sections at several sites showing the location of woody vegetation. His plots showed more woody vegetation between the toes of the channel and on the sides of the channel in the downstream reaches. The State's field sketch maps of cross-sections had not shown this (10/1 at 45-51, 55-63).

From his comparisons, Gabbert concluded that the State's methods were inadequate to show a decrease in channel capacity below the diversions. Their own vegetation data indicated vegetation was filling in the channel on both sides, reducing channel capacity. The State's witnesses had strongly emphasized the variability in the stream channels; however, Gabbert suggested that this could just be due to their field methods (10/1 at 51-52, 73-80).

Additional Measurements at Diversion Sites by the U.S.

Mapping

In 1989, Collins was asked to map the Fraser River, Lost Man Creek and Beaver Creek above and below the diversions. Harvey had testified that the first two sites had different geomorphic-geologic settings upstream and downstream, and that Beaver Creek was influenced more by beaver dams than by the diversion. Collins put a great deal of effort into describing vegetation and geomorphology along the channels and preparing maps which showed that at least individual reaches of the upstream and downstream channels were in fact very similar and that streambed materials were typically alluvium (Andrews 12/10 at 153-154). She mentioned that the "old bankfull" level was very difficult to identify below an 1880's diversion on Beaver Creek where cattle grazing had affected the banks (11/21 at 17-21).

Collins' mapping procedure was very detailed. It involved setting out about 5 pairs of stakes across a study reach, stretching tapes between them, and then running a center line tape of about 300 feet down the reach and across all of the cross-section tapes. The position of the center line at the taped cross-sections was recorded, as were the bankfull widths. The Forest Service surveyed elevations of the stakes. Using the center line as a reference, Collins measured out perpendicularly from it to the bank using a rod, in order to describe the shape of the channel. Measurements were typically taken at intervals of about 5-6 feet; sometimes 10 feet. She sketched the configuration of the bank between these measurements in the field, and drew in details such as: thalweg location, channel bed materials, individual boulders, woody debris, width of undercut banks, etc. These features were mapped using color-coding (11/19 at 68-83). The judge described her maps as "impressive testimony" and "a little short of monumental" (11/20 at 21-39).

By comparing her maps to the State's, Collins found major differences in plan form and the locations of features such as an avulsion channel. She concluded that her mapping was more reliable (11/19 at 111-115).

She went through a description of each of the three sites and compared measurements taken from her maps to those obtained by the U.S. and State. In general, her measurements of width upstream of the diversions agreed with both SLA's and the Forest Service's upstream widths, and with the downstream "old bankfull" width. Her "new bankfull" widths downstream were smaller than the "old bankfull" widths, as the Forest Service had found. She also found vegetation growing between the "old" and "new" bankfull levels downstream of the diversions. An "area index" computed by multiplying depth by width decreased downstream for SLA's, the Forest Service's and her data at all sites (11/20; 11/21).

One of her conclusions was that "comparable" sections could be found upstream and downstream for comparison. For example, for the Fraser River site, she showed that sites with comparable slopes still indicated a decrease in width downstream. Harvey criticized the U.S.'s implication that local reaches with similar characteristics above and below diversions could be compared. He said those reaches were part of a larger system; e.g. a bench above a waterfall wouldn't be the same as a flat segment on the plains (9/18 at 96-102).

Angel brought out that Collins' width measurements at the Fraser River were generally wider than the Forest Service's - by up to 6 to 10 feet. Collins said she might not have measured at the same locations. She also did her measurements in a different year, and mentioned some aggradation had occurred in the interim (11/21 at 107-124).

1990 Total Station Surveys at Diversion Sites

One of the State's criticisms of the Forest Service's diversion studies was that there was so much variability in the streams that one cross-section above and below wasn't a good comparison. They had also said that at some sites, substantial differences in slopes above and below also made comparisons invalid. In response to these criticisms, the Forest Service collected additional cross-sections in 1990 and re-measured channel gradients both above and below diversions. The intent was to substantiate the 1989 data and conclusions (Silvey 11/15 at 12-14).

They collected additional data at all diversion study sites except Jefferson Creek. The diversion site on the West Branch of the Laramie River visited during a field trip was added. The 1990 cross-sections were located within the same general area as the 1989 sites, but primarily on relatively straight sections. Field procedures were essentially the same in 1990 as in 1989 with the exception that most of the surveying was done with a total station (Silvey 11/14 at 151-155; 11/15 at 14-16, 128).

Silvey wasn't present during the surveying so didn't know how the total station was set up. He believed in most cases they also used a tape at the cross-sections. The U.S.'s team apparently surveyed a reach slope upstream of the diversion as an average through three cross-section locations, whereas downstream they measured local slopes at each cross-section (Silvey 11/14 at 151-160; 11/15 at 33-41).

Gabbert said all surveys were "closed." Initially, this was done using a closed loop method, but later in the summer they used another method based on a built-in feature of the total station, with which they could check angles and distances at each turning point. This kept them from having to re-traverse the steep channels. Gabbert said both methods were accepted procedures, and he believed the surveys were accurately closed. The maximum closure after covering several thousand feet of channel was about 1.5′ vertically and 2′ horizontally (10/1 at 80-93).

Gabbert compared these precision surveys to the longitudinal profiles constructed by the State to illustrate their inaccuracy. Bearings and distances were both off. For example, at Rapid Creek the State had obtained an upstream slope of 47% and the U.S. 60%. At one section, Gabbert said the State's team couldn't get into the stream because it was steep, and the measured horizontal distance was off by 90 feet (10/1 at 96-103). Gabbert concluded from his comparisons that the State's representation of the actual topography was not fair and accurate. He also said their work was not repeatable. Because of these flaws, he would not rely on their data or maps to form scientific opinions on channel conditions at the diversion sites (10/1 at 111-116).

Silvey discussed the results at these sites (11/15 at 25-31):

- Bennett Gulch: Surveys from 1990 supported the 1989 surveys in showing a change in channel condition from upstream to downstream of the diversion. The currently active channel had a cross-sectional area of 8-10 square feet above the diversion and 3-5 square feet below.
- Quarter Mile Creek: Surveys from 1990 agreed with the 1989 surveys. There was a difference in the upstream and downstream bankfull areas. There was also a difference in slopes: 30% upstream and 11-16% downstream.
- Jefferson Creek: The State had suggested that the upstream reach was in a mountainous area whereas the downstream reach was in a meadow and therefore a comparison wasn't fair. Silvey said the U.S. data showed a change in channel capacity from upstream to downstream. He agreed that the topography and land forms were perhaps different, but he still attributed the change in cross-section to the reduced flow regime.

Silvey concluded from the work done at the diversion study sites in 1990 and in previous years that stream channel gradient may have some influence on channel configuration but it was not "the singular element that causes the type of changes that we observed below these diversions." Reductions in channel capacity downstream of diversions had occurred between the new and old bankfull levels due to sediment accumulation and vegetation encroachment. It was these areas which would adjust if the total flow were put back into the stream.

Silvey also found that the increase in the number of cross-sections surveyed in 1990 didn't change the U.S.'s conclusions. The 1990 data simply reaffirmed and substantiated earlier conclusions, even though some of them were based on only one cross-section above and below the diversions (11/14 at 26-27; 11/15 at 16-24, 31-32).

The Forest Service had not collected additional vegetation data in 1990 other than visual observations (11/15 at 73-83).

The opposition challenged the U.S.'s 1990 EDM surveys by saying if the EDM had been used to measure cross-sections without a tape being stretched across the channel, the cross-sectional data could have been in error because the rod person might not have walked straight across the channel. The State had constructed a plan-view plot from some of the cross-section data using the U.S.'s horizontal coordinates. These showed that some survey points weren't lined up on a straight line across the sections (Sansone 11/15 at 138-154).

Sansone criticized the Jefferson Creek results, pointing out that the old bankfull width below the diversion was considerably larger than the upstream bankfull width. Sansone argued that if the reaches were truly comparable, they should have been about the same. Silvey said the stream might become slightly wider as it moved out of the mountains. The old channel was harder to find below the diversion. For this site, the upstream and downstream slopes were virtually identical and the bed material sizes were similar (11/15 at 136-138).

The State's Withdrawal of Its Slope Measurements

After the U.S. did their precision surveys in 1990, the State's team went back to the Fraser River site to verify their own surveys and discovered their clinometer was giving inconsistent results. It was a newer design with a "sight prism" which caused parallax problems. By testing its results against an engineer's level, Harvey and Mussetter found it gave as much as 10% error. It tended to give lower numbers when sighted uphill and higher when sighted downhill. Therefore the errors were not entirely random, but the actual amount of error was not known (Harvey 9/18 at 12-27).

Because of the faulty clinometer, Harvey said the State's longitudinal profiles and the slopes measured above and below diversion sites were incorrect. The largest error was on North Lone Pine where they had measured a 12.8% slope but it was actually 6.8%. Harvey believed the error didn't affect the plan view maps because the error was only equivalent to the thickness of a pencil lead in the horizontal direction (9/18 at 32-35).

Angel made a motion to withdraw all of the State's exhibits which had been based on the erroneous slope data (9/18 at 124-125).

Harvey still believed a clinometer was adequate for this type of survey because he had previously obtained good agreement between longitudinal profiles obtained in this manner and with an EDM (9/18 at 27-32). He purchased two new clinometers (of an older design) and he and Mussetter re-surveyed the Fraser River site and a steeper site. They found they could duplicate the Forest Service's measurements, and concluded that their measurements had the same margin of error because the Forest Service hadn't closed their surveys. Because of the good agreement, they decided to accept the Forest Service's slope data, and just re-surveyed the sites where the Forest Service hadn't collected data. During this survey, they back-sighted every shot as a check (Harvey 9/18 at 35-39, 76-79).

They found that Lost Man Creek now had roughly a 3-fold increase in slope from upstream to downstream. Rapid Creek was 53% upstream and 22% downstream (9/18 at 39-45, 50-52). Harvey said the revisions in the slope data did not change his conclusions, and he still believed the differences in above/below channel widths and depths could not be attributed to the diversion because of other factors, including slope. He again said the Forest Service's data did not demonstrate the adverse impacts they had claimed would occur, even though some diversions were 100 years of age or more. Channel maintenance flows were therefore not needed (9/18 at 52-54; also Li 6/7 at 76-78).

Section 6.
Sediment Transport in Mountain Streams

OVERVIEW

Both sides collected and analyzed massive amounts of data on sediment transport in Colorado mountain streams. During the trial, they criticized methods used by the other side and disagreed on the amount of sediment transported in the streams and its relevance to channel adjustment and maintenance. The main points of the U.S. and the opposition are summarized in Table 3.

All three of the U.S. policy witnesses were asked if they knew of complaints from the public about reservoir siltation, about diversions causing increased sediment, or about channel instability due to diversions reducing flows. Leonard (1/17 at 58-9) and Reynolds (1/18 at 109) both said they had no knowledge of any complaints. Cargill (1/22 at 74, 91) only gave one example from a ranger complaining about deteriorating CCC structures. Angel, attorney for the State, implied that since the Forest Service had not received complaints about any adverse effects of existing water diversions, then operation of those rights had therefore not entirely defeated the U.S.'s purpose of securing favorable conditions of water flow (1/17 at 60).

Table 3.—Summary of points made by the U.S. and opposition on sediment movement in mountain streams (Andrews 2/14 at 79-83; 12/10 at 120-121; Schumm 3/21 at 129; 3/22 at 10-11; Richardson 7/25 at 49-85).

U.S.	Opposition
Sediment supplies were of sufficient quantity to fill in the channels if maintenance flows were not provided.	The amount of sediment transported by the mountain streams in WD1 was very small and mostly washload. Only small flows, if any, were needed to move this sediment.
Materials forming the stream boundaries moved at bankfull flows or even less.	The stream boundaries were composed of coarse materials which would not move at bankfull flow.
The streams were **hydraulically-controlled**, meaning there was a unique relationship between discharge and the amount of sediment transported. If flows were reduced but sediment supply remained the same, then aggradation would occur.	The streams were **supply-limited**, meaning there was less sediment available than what the streams could carry. Flows could be reduced and the streams would still be able to carry the available sediment.

A number of witnesses for the opposition testified about sediment problems in Water Division 1, including water commissioners, members of water boards, and ditch operators. All testified that sediment problems were minor and limited to routine maintenance except after a few catastrophic flood events, such as the 800-1000 year flood on the Big Thompson and the Lawn Lake dam failure in Rocky Mountain National Park. They pointed out that on-channel reservoirs were designed for some sediment accumulation (6/24 at 41), and that many of the ditch headgates built as early as the 1870's had "sand traps" or "sand gates" to divert sediment away from or out of ditches and back to the main channel (6/26 at 109-110). The opposition witnesses testified that they had seen some minor sediment accumulations, but not to the extent of plugging streams or causing problems - and had not received any complaints of that nature (6/26 at 130; 6/27 at 47, 71). Some of the Colorado water administrators also made the point that sediment could actually be beneficial, for example by sealing ditches and reducing seepage losses (6/26 at 38; 6/26 at 110). During high runoff, suspended solids and associated nutrients were deposited on farmlands, and were also considered a benefit (6/24 at 41).

These opposition witnesses said the National Forest streams were much rockier, steeper, and had less sediment in the water than lower elevation streams, and that floods stayed within the streambanks. In the lower elevation streams, the streambanks had more clay, the streams meandered, they had higher sediment loads and they flooded overbank. Sediment transport in the upper streams consisted of a few large rocks rolling a short distance, whereas downstream there was more fine material which stayed suspended. In the mountain streams, diversion headgates did not experience sediment buildup and did not have sand traps (6/26 at 126-9; 6/27 at 63-4). The opposition argued that the Forest Service should have done a sediment budget to determine where the sediment was carried, and how much sediment was contributed to streams based on stream channel classification, discharge volumes, and natural and human activities (1/22 at 67).

BASIC PRINCIPLES AND PROCEDURES

Classification and Measurement of Sediment Transport

Sediment transport could be categorized in several different ways (Richardson 7/25 at 94-97; 7/26 at 132-133; Leopold 1/24 at 56-57; Mussetter 6/20 at 62-64):

- Based on how it moves:
  - **suspended load:** is suspended in the flowing water by turbulent eddies. It moves faster than bedload.
  - **bedload**: moves by rolling, saltation or hopping along the streambed. It is "pushed" by the water. This "pushing force" was correlated with velocity and could be expressed as a shear stress.
- Based on its source:
  - **bed material load: is** material contributed by the streambed. The amount which a stream was capable of moving could be calculated using hydraulic variables and a sediment transport equation such as Meyer-Peter Muller, Einstein or Parker.
  - **washload:** this term was developed by Einstein. Washload was always carried in suspension and "washes through the system." It is not found "in appreciable quantities in the bed." The amount moving through a section could not be determined by hydraulic calculations.
- Based on how it was measured:
  - **suspended sediment sampler** (measures to within 3 inches above the streambed)
  - **bed load sampler** (e.g. Helley-Smith—it could be used to capture the "unmeasured load" within 3 inches of the streambed).

Suspended sediment was commonly measured with a **USDH48 suspended sediment sampler** which collects an integrated sample over the depth of the water column through a 3 mm nozzle. The sample (water and sediment) is then taken to a lab where it is filtered. The sediment trapped on a filter is dried and weighed, and the weight is expressed as a percentage of the total sample weight (Leopold 1/24 at 58-59).

Bedload could be measured using a variety of methods. Leopold said particle movement had been studied by using radio transmitters in rocks, fluorescent sand, and in Israel with "magnet rocks" located with a coin finder. Sediment could also be caught in "traps" excavated in the stream channel. Weir ponds were often constructed to "still" the water level for streamflow measurements, and they also served as sediment traps. A classic sediment study was performed on the East Fork River in Wyoming where an elaborate sediment trap was constructed across the entire channel with a conveyor belt to move the sediment to a collection area. In conjunction with this same study, Dr. Bill Emmett of the USGS tested the Helley-Smith bedload sampler to evaluate its sampling efficiency. It would later become a standard field instrument.

The **Helley-Smith bedload sampler** catches sediment moving through a square 3" entrance into a nylon bag (in the WD1 case, 6" samplers were also used). Samples are dried and weighed, and sediment transport calculated using: sample weight, the time the sampler was immersed in the stream, and the water discharge. Rosgen (2/12 at 81-84) said that the movement of bedload sediment was very random, describing it as a "very surging, disoriented . . . type of a movement." Therefore the sizes and amounts of material caught could vary considerably from one sample to the next. This was particularly true for the larger rocks.

Richardson mentioned that a Helley-Smith sampler couldn't be used in sand channels because placing it on the bed would disturb the bed material, causing more material to be caught than what was actually moving. He also made the clarification that sediment sampled with a Helley-Smith sampler was really "bedload contact load." At the sites in WD1 where his team took samples, he said the material captured probably wasn't bed material load—it was just particles moving across the streambed surface (7/26 at 119-127). In a watershed study in Wyoming, Wilcox found that sediment size distributions were similar between Helley-Smith samples and the sediment trapped in a weir pond, but that the Helley-Smith sampler underestimated the volume of sediment (2/7 at 26-35).

Samples of either suspended or bedload sediment could be sieved or directly measured to obtain size distributions. These were commonly plotted as gradation curves which showed cumulative percentages above each sieve size (see Figure 5).

From these graphs, particle sizes of particular significance such as the D_{50} (50% smaller, 50% larger) or D_{84} (84% smaller) could be read (Leopold 1/24 at 70-71).

Sediment transport rate was the amount of sediment moving through a channel over time, and was expressed in units such as tons/day or grams/second (Leopold 1/24 at 57). The opposition used units of cubic feet per second. Even with samplers, only a portion of the total load was collected and the transport rates and total amount moved had to be inferred from "point" sediment and discharge measurements (Andrews 2/14 at 89-90). Leopold said that in the Colorado streams, suspended and bedload amounts were about equal, in comparison to most rivers in which suspended load tended to be greater (1/24 at 74).

Pavement and Armoring

Witnesses on both sides discussed the terms "armor" and "pavement." Both terms referred to a coarser layer of material on the streambed surface which covered finer materials beneath it and inhibited their movement. It was not present in all streams (Mussetter 6/21 at 101-102). Andrews used the term "bed surface" to generally describe these features, and said there was not much agreement on their meaning (2/14 at 48). He and other witnesses gave these definitions:

- **pavement:** U.S. witnesses said this was the preferred term for a coarser layer of bed surface materials formed and maintained by sediment movement. This layer would become mobile under frequently occurring flows. **Subpavement** was the material beneath the surficial layer which contained finer materials as a result of sorting processes (Rosgen 2/13 at 88-89; Andrews 2/14 at 48; Silvey 1/31 at 59). Rosgen (2/8 at 172-173) gave an example from a stream in WD1 where the D_{50} of the surface was about 70 mm, whereas the subpavement D_{50} was only about 8 mm. The respective D_{84} values were 110 mm and 30 mm.

  The material contained in bars was believed to be representative of the bedload sizes moving at bankfull discharge. The subpavement was the supply for bedload, and the pavement layer acted as a "buffer zone" to regulate the amount of subpavement material available for transport. U.S. experts maintained that bars, bedload and subpavement materials should have similar sizes (Rosgen 2/8 at 173; Walch 6/21 at 81-83).

  Opposition witnesses defined pavement as a "relic feature," e.g.. related to glacial processes. The U.S.'s description of pavement didn't apply to boulder torrents with step-pool morphologies where it would not be breached by the normal range of discharges experienced (Harvey 4/5 at 19-22; 32-35; Mussetter 6/21 at 81-83).

- **armor**: This was a coarse surface sediment layer which was formed when finer particles were winnowed away from around the larger particles, leaving them behind. Armor layers were common below reservoirs where there was no supply of sediment from upstream and the coarser materials remaining were not moved by reservoir releases (Rosgen 2/13 at 88-89; Andrews 2/14 at 48; Madole 1/23 at 98).

  Harvey, an opposition witness, said the term armor commonly referred to a coarse layer which was immobile at certain discharges, but would "breach" at higher flows. Sediment below the armor layer had a more heterogeneous mix of particle sizes. One rule-of-thumb index of whether a channel was armored or not was the square root of the ratio (D_{84}/D_{16}). If this was close to 2, then the streambed was probably armored (4/5 at 19-22, 32-35).

Affect on Sediment Transport

The presence of a coarser surface layer influenced sediment transport. In one of Parker's papers, he had stated that the pavement layer was first "broken" at a critical water discharge. When discharges exceeded this value, more and more of the pavement was moved, exposing the finer subpavement materials. Bedload transport was then governed by hydraulic conditions. When discharge was much below the critical value, the bedload consisted mostly of small amounts of fine material moving over the pavement, and transport rates were governed by availability because the finer streambed materials were protected by the pavement (11/14 at 122-127). The U.S. believed the WD1 stream channels would generally reach the critical value at bankfull flow; the opposition believed they wouldn't.

Figure 8 contains some terms and principles relevant to sediment transport.

Hydraulically Controlled vs. Supply-limited

Mussetter defined a **hydraulically-controlled stream** as one which was capable of moving virtually all of the sizes of material in the streambed. The amount transported was a function of the water's energy. For example, in flatter sand-bed streams where there was essentially an unlimited amount of transportable material in the bed, it could be assumed that whatever was being carried was only limited by the energy of the water. A

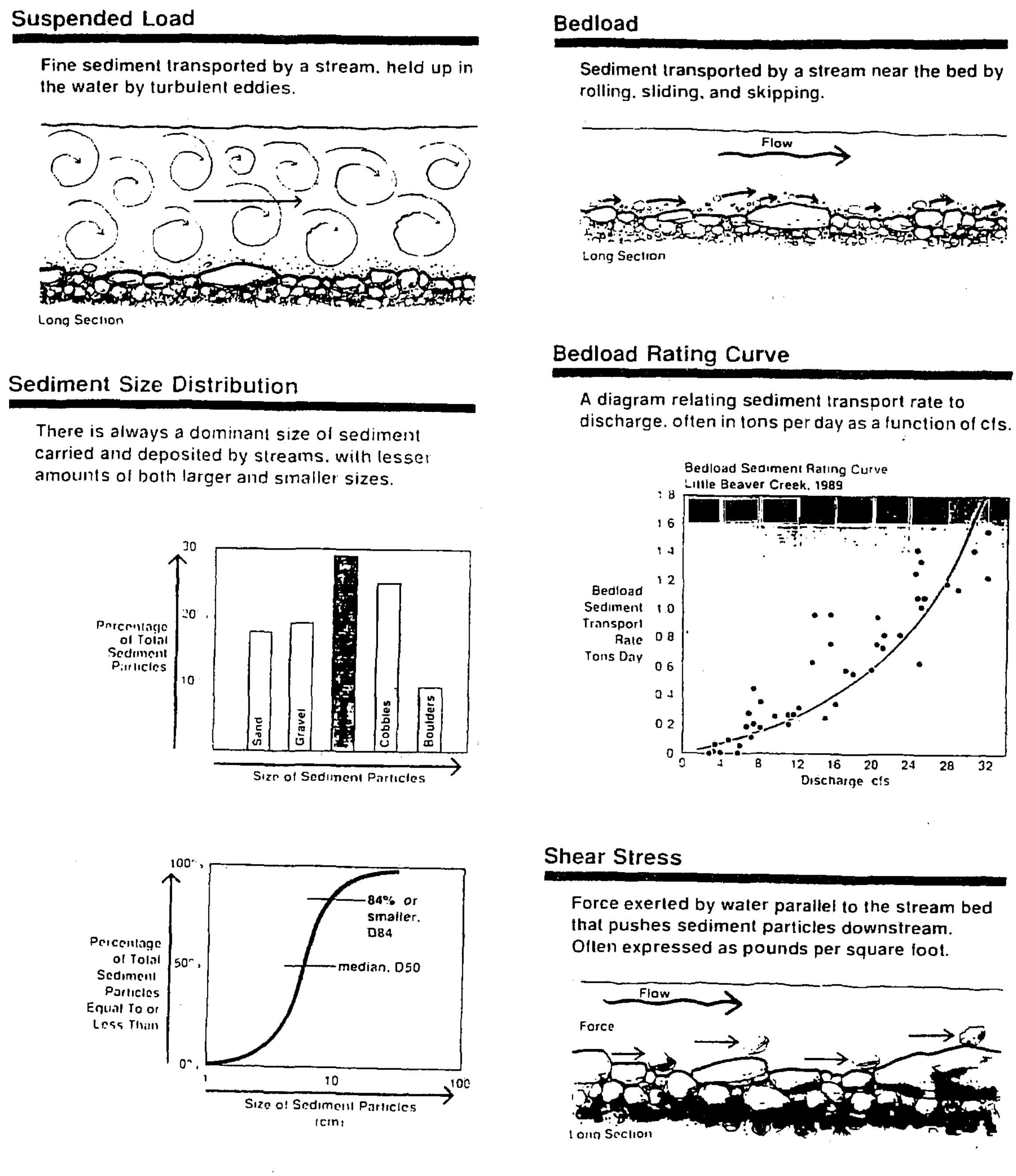


Figure 8.—Sediment transport: terms and principles. From Exhibit [A-327].

supply-limited stream was not carrying as much sediment as it could, and sediment transport was controlled by the availability of material (6/12 at 160-162, 168-169).

In general, transport capacity was generally larger than supply for small particles (e.g. suspended load). For larger particles (e.g. bedload), capacity was generally much less than supply and their movement was controlled by hydraulics (Leaf 8/6 at 31-38, 45-50, 138-139).

The consequences of flow reduction would therefore be different in hydraulically-controlled and supply-limited streams. In a hydraulically-controlled stream, there was normally a balance between the sediment supply and the amount carried by the stream. If flows were reduced, aggradation would be expected because the sediment supply wouldn't change. However, in a supply-limited stream, the capacity to carry sediment was much higher than the amount being delivered to the stream; therefore the flows could be substantially reduced and they would still be able to transport the delivered material without aggradation. The opposition believed that flows could be reduced substantially in the WD1 streams without causing aggradation. Walch made the point that the supply limitation also depended on the sizes of materials being provided to the stream, and the WD1 streams had an abundance of gravels and cobbles to be moved but a shortage of finer materials (Musetter 6/12/90 at 139-141, 160-162, 168-169; 6/19/90 at 36-37).

Summary of Concepts on Sediment Movement

The U.S.'s Viewpoint

Rosgen summarized the U.S.'s concepts of how sediment moved in channels. Overall, as discharge increased, there was a tendency for the volume and size of particles moving in channels to also increase. At bankfull flow, a large portion of the material making up the subpavement and bars would move. At the beginning of a runoff event, low flows "winnowed away" finer materials from around larger particles, creating "pockets." As the flow increased, the pockets deepened and the larger particles could then begin to roll. This would then loosen materials stored upstream of the larger particles, which also began moving. Therefore, the sediment actually moved in "waves" of mixed sizes: gravel, cobble and sand. Higher percentages of larger particles tended to move at higher flows, but there was a great deal of variability in the relationship, and the larger particles could be underestimated because of their random movement. These large particles tended to move on the slope of the channel, particularly at side slopes where flows converged—rather than the deepest part of the thalweg where shear stress was greatest (2/8 at 175-179).

Rosgen went on to explain that a sediment particle took more energy to move once it came to rest than it did to keep the same particle entrained (2/9 at 150). Part of the reason was due to the fact that velocities were lower near the streambed and at depositional sites. So once a particle was deposited, there was a higher probability of it staying there and developing an island or bar which would eventually become vegetated (2/9 at 150-151).

The Opposition's Viewpoint

Harvey argued that erosion and deposition in the WD1 streams tended to be local processes and involved a "veneer" of sand moving across the coarser streambed materials. The larger particles governed the adjustability of the channel perimeter. Transport of the sand "veneer" did not depend upon mobilization of the streambed. Harvey disagreed with the conclusions of U.S. experts that the beds of the WD1 channels would mobilize at U.S. defined bankfull flows (4/5 at 49-52). He had observed an increase in bedload when armor layers breached in New Zealand streams, but not in WD1. He did observe armoring at all of the WD1 streams he visited. However, he believed these coarser surface materials would only be transported by larger, rarer events (4/5 at 41-42, 44-49).

In Harvey's Ph.D. study, he had taken bedload measurements on the Little South Fork of the Poudre River. Early in the season, finer-grained material stored among or hidden behind coarser rocks was transported, and this was exhausted on the beginning of the rising limb of the snowmelt hydrograph. After the supply was exhausted, there appeared to be a very low transport rate until the lower-bank armor was overtopped and flows could erode finer sediments on the channel banks. Bedload transport increased again after this occurred. However, the streambed armor did not breach during the study even though the peak discharge exceeded ¾ bankfull flow. He also saw a very fine sand-silt bar erode out when the water rose, but it re-formed later (4/3 at 687-691).

Based on his and other research, Harvey believed that sediment yields from the national forests were low, the sediment transport rates were low, and the streams were supply-limited. He agreed that some sediment was moving through the channels, and that sizes could range from fine grains up to cobbles, but that coarser materials didn't move at frequently occurring flows (4/3 at 689-91; 4/5 at 23-27, 62; 4/9 at 28, 42).

SEDIMENT SOURCES IN WD1

One of the assertions made by the U.S. in the WD1 case was that sediment would continue to enter channels from hillslopes and tributaries over time, and if channel maintenance flows were not provided, this sediment would accumulate. The U.S. experts provided evidence of processes which contributed sediment to channels. The opposition witnesses testified that the amounts involved were very small.

General Observations and Processes

The U.S.'s Viewpoint

According to Madole, the principal agents of erosion were: water, glacial ice, wind and gravity. He said one of the most important processes was unconfined sheet flow from slopes and streambanks. This process could be accelerated by wildfires (1/23 at 43-47). Madole (10/4 at 56-88) presented photographs to illustrate sediment sources in the Colorado mountains, including examples of:

- valley flat sediments; i.e. alluvium deposited during previous periods of aggradation or in alluvial fans, which was available to a stream when it eroded its banks;
- tributary sediment delivered to valley flats by tributaries ranging in size from gullies to large creeks. Madole said some of the tributary watersheds were affected by fire, and that fire was common. He had observed layers of charcoal in alluvial deposits;
- avalanche tracks, alluvial fans, and debris flows which delivered sediment to the valley floor;
- sheet wash and rilling on steep valley sides, exposed roots indicating slope wash;
- a stream undercutting the foot of a slope, causing material to slide into the creek; streams cutting into fine-grained till in glacial moraines;
- mass movement, e.g., rockfalls, debris flows, and landslides;
- sediment accumulations behind LWODs and diversions, and in reservoirs.

Madole said he had not quantified the relative amounts of sediment from different sources, but believed there would be variations within and between life zones.

Rosgen had observed that surface erosion was generally low in most of the forest lands except the granitic areas in the southern part of WD1 which had a high drainage density, deep dissection of the terrain, and a substantial amount of surface wash and surface erosion. Other areas had good drainage and vegetative cover (2/13 at 30).

The Opposition's Viewpoint

It was the opposition's position that sediment yields in the forested mountain watersheds were very low. Schumm made the point that the drainage network only made up a very small part of the total fluvial system, on the order of 1% of the drainage area. The rest of the area, the forest, affected stream channels because it controlled the amount of water, sediment and sediment sizes supplied to them (3/21 at 59, 64).

- Hillslope erosion was low and sediment didn't reach the channels

Schumm believed that overland flow was uncommon in WD1. He hadn't seen rills and small channels which would indicate large quantities of surface runoff, and he believed only fine materials would be delivered to streams in areas where overland flow did occur. He had also read recent studies which indicated that forest fires did increase sediment yield, but that most of the sediment was fine-grained, and sediment deliveries decreased quickly as soil infiltration rates recovered (3/22 at 9-10). Leaf (8/6 at 140-141) also mentioned that even the major fires in Yellowstone had not caused large-scale introduced sediment and channel damage.

Schumm had developed his opinions about sediment yields in WD1 streams from his observations that only fine-grained sediment was trapped behind beaver dams and in one reservoir. Schumm admitted that his observations on sediment yields and transport were more "common sense than quantitative" (3/22 at 10-11, 65).

Schumm cited studies by researchers in Colorado who had found that sediment didn't reach the stream channel because it accumulated at the base of slopes or in alluvial fans (3/21 at 73; 3/22 at 9-10). Harvey also observed that most of the material coming off hillslopes was fine-grained and was stored at the base of hills. He had been in the WD1 forests during intense rains and hadn't seen much evidence of sheetwash. However, Harvey did believe tributaries could deliver sediment to the main channels as evidenced by fans forming at the confluences—especially on ephemeral streams (4/3 at 695-697).

Trout referred to a 1986 book, *Hillslope Processes*, with a chapter written by T. Nelson Caine about research in the mountain areas in WD1. Caine had written that almost all sediment remained on hillslopes except for silt and clay, and this had been true for most of the Holocene. Madole said Caine was mostly talking about high alpine areas. He also quoted Caine as saying (10/4 at 161-168):

"anyone who generalizes from the few studies in mountainous areas is likely to be embarrassed by the conclusions drawn."

- Site-specific factors should be evaluated

On numerous occasions, Trout, an attorney for Northern, criticized the U.S.'s work because they hadn't done a sediment budget on a site-specific basis to evaluate the effects of altering the streamflow regimen (1/25 at 111-112). They hadn't looked at the sources of sediment, e.g., bed, bank, side, or "dropped out of the sky." Rosgen said the U.S. researchers hadn't found any of "them sky droppers," but agreed that they hadn't done a detailed study on sources (2/13 at 28). Leopold said sediment source data were "not easily available" and said the U.S.'s procedures were used despite the fact that there were differences in sediment inputs (1/25 at 111-112).

Leaf believed the following site-specific factors needed to be evaluated and monitored for each stream (7/31 at 25-30, 79-80; 8/1 at 108-117):

- Hydrology: High elevation runoff was dominated by snowmelt, whereas lower elevations had a snowmelt component plus rainfall components. High-intensity rainfall generally occurred below 7000 feet (8/2 at 30-38).
- Sediment sources: According to Leaf, there were generally two sources of sediment available to stream channels (7/31 at 88-89):
  - flow-induced sediment (from within channels),
  - introduced sediment (from surface erosion on hillslopes).

  In the higher elevation streams, the amount of flow in the channel was most significant in determining sediment loads, whereas in the lower, rainfall-influenced zones, introduced sediments from outside the channels were more significant. Leaf disagreed with Madole who had said unconfined runoff was a pervasive source of sediment to the stream channels in WD1.
- Channel processes: Bedload, suspended load, channel geometry and the sizes of materials transported by the stream varied from one stream to another. The ability of stream systems to absorb changes in flow or sediment would also vary.

Leaf said hydrology, sediment sources and channel processes were interdependent, but were related differently in alpine, subalpine, montane and semi-arid zones. He estimated that about half of the U.S. quantification points drained watersheds which were all or mostly in the subalpine zone (8/1/90 at 110-117). Many of these streams also drained areas in the alpine zone (above timberline) (7/31 at 32-39; 56-57). Leaf concentrated his discussion on the subalpine and montane zones:

- **subalpine zone**: This zone extended upwards from about 7500 feet to timberline at about 11,500 feet. Soils were deep and the slopes typically well-protected by heavy forest cover. High infiltration rates precluded any overland flow and surface erosion of significance (7/31 at 32-39, 56-57). Runoff predominantly occurred during the snowmelt season and rainfall effects were relatively insignificant. Typically, a stream would begin to rise in the first part of May, peak in the middle of June, and then go through a recessional period. Typical water yields were 5 to 38 inches in subalpine zones in Colorado and Wyoming (7/31 at 39-44).

  Leaf emphasized the fact that subalpine areas had a **variable source area hydrology.** Snowmelt waters soaked into the deep, permeable soils and migrated down through the soil mantle to lower slopes which became saturated, created seeps, and contributed water to the streams. The streams were generally **gaining streams** because they received a constant inflow from the hillslopes. The source areas expanded and contracted during runoff events, corresponding to changes in the runoff hydrograph which peaked when the source areas reached a maximum size (7/31 at 50-54). A 1985 paper by Troendle described research done in the Fraser Experimental Forest in which lysimeters were placed in a road cut at the bottom of a slope to monitor soil water movement. It was most prominent in the 3 to 13 foot zone (7/31 at 45-48).

  Leaf said the fact that these forest streams received water from subsurface sources rather than overland flow was often unrecognized. In his opinion, surface erosion and introduced sediment was negligible in the subalpine streams. He also believed that soil creep, landslides, avalanches, debris flows and gravity were not significant sources of stream sediment, and cited a paper by Andrews who had supported the idea that these processes were "much less active at present than in the past" in Colorado rivers (7/31 at 89-91).

Strahler had found that sediment yield was closely related to drainage density, with densities on the order of 3-8 miles/square mile associated with erosion-resistant basins. Leaf had computed densities of 4.8 to 8.3 for three streams on the Fraser Experimental Forest in the Rocky Mountains to the west of WD1, indicating that these subalpine streams would have low sediment yields (8/6 at 68-70). Troendle, a U.S. witness (12/3 at 50-53) agreed that surface runoff and surface erosion were not major factors on those watersheds.

Leaf concluded that most of the sediment load in the subalpine streams was derived from erosion of the beds and banks of the channels themselves; however, even this was relatively minor in the stable WD1 streams. Therefore, the total amount of sediment transported by these streams was quite low (7/31 at 88-89, 103-105, 141-155).

- montane zone: This was the same as the "Ponderosa pine zone," and was generally between elevations of 6000 and 9000 feet along the lower part of the Front Range. These areas received summer rainfall as well as intense spring rainfall associated with convective storms. They had less timber cover and soil protection, shallower soils, and the stream channels were more unstable than in the subalpine zones. The annual precipitation of about 15-20 inches per year did not support a dense understory growth (7/31 at 107-110, 126-127).

November to March was a period of soil moisture recharge when the ephemeral snowpacks at lower elevations melted. In contrast, in the subalpine zone the soils were typically dry as snowpacks accumulated. In the montane zone, there was only a slight base flow, if any, during the November-March period. Snowmelt runoff occurred from April to May. After that time, vegetation used up the soil moisture, and the forests generally entered a period of moisture stress during the summer. Summer rainfall could replenish some soil moisture, as well as causing a response in the streams (7/31 at 115-118).

Leaf showed a hydrograph for a stream with a watershed partly in the montane zone. It had runoff "spikes" from rainfall events and was more flashy than a snowmelt hydrograph (7/31 at 111-114).

Sediment yields in the montane zone were highly variable and episodic in nature. Studies of sediment deposits in reservoirs had shown that as much as 30 to 60% of sediment came from gully sources (7/31 at 128). One of Leaf's publications stated that 90% of the Front Range area in the montane zone consisted of less fertile, shallow granitic soils which were potentially unstable. Episodic high intensity rainfall-runoff events were responsible for gully formation and high sediment yields (8/6 at 76-82).

Walch added that none of the quantification points were above 11,500 feet and only 14% were below 7000 feet. About 50% were in the montane zone between 6000 and 9000 feet, and 37% were between 7000 and 9000 feet (8/2 at 30-38). There was therefore a high percentage of the sites which would be expected to have high sediment yields.

Sediment Yield from WD1 Streams

Schumm's book The Fluvial System contained a statement about sediment yields per unit area being greater for small drainage basins than for large ones, or areas of about 2000 square kilometers. He said the data leading to this conclusion mainly came from highly erodible soils in agricultural areas. However, for the WD1 streams where the headwater channels were composed of large rocks and the plains streams flowed on more erodible materials, he believed the sediment yield per unit area would increase in the downstream direction, and would be much higher on the plains streams (3/21 at 67-70, 129-130; 3/27 at 24; 2/5 at 86).

Rosgen presented data from USFS research sites in the Rocky Mountains, for which bedload yields averaged 0.016 to 0.03 tons per acre per year. Rosgen said these values were not very high. He said the A2 streams yielded less bedload at 0.009 to 0.017 tons/acre/yr than a B1 stream at 0.053 tons/acre/yr, which he said would be expected (2/9 at 163-170).

Schumm similarly estimated that sediment yields from the WD1 streams were on the order of 0.01 to 0.02 tons/acre/yr based on the literature, his field observations, and the data collected by the Forest Service for the WD1 case. Mussetter had calculated 0.02 tons/acre/yr from Rosgen's data in WD1 and

0.027 tons/acre/yr from Wyoming data given by Wilcox. Schumm said these amounts were very small when compared to 5 or more tons per acre per year tolerance levels for agricultural lands (3/21 at 74). In his opinion, the Forest Service was "making a great issue of very high sediment yields when their own data shows that it is relatively low" (3/21 at 75). Using a conversion factor of approximately 0.45 cubic yards/ton, Schumm estimated that 0.02 tons/acre from a 10 square mile watershed would amount to about 9 truckloads at 4 cubic yards each (3/21 at 124-128).

Other sediment yield data presented in the WD1 case included:

- Published data on sediment yields from 50 watersheds in Colorado summarized in a dissertation written by one of Li's Ph.D. students. These varied from 0.016 to 1.6 tons/acre/yr (Li 6/7 at 102-104, 142-143).
- Leaf presented several sediment yield data sets from subalpine, montane and semi-arid areas in Colorado to demonstrate that sediment yields varied across climate zones (7/31 at 98-103, 141-155):
  - subalpine zones had low sediment yields; e.g. an average precipitation of 30 inches per year corresponded to about 0.016 tons/acre/yr or less;
  - at lower precipitation zones, sediment yields were higher. For example, a site on the Manitou Experimental Forest in Colorado had an average precipitation of about 15 inches per year and a sediment yield approaching 0.94 tons/acre/yr.
- Sediment yields from forested lands in the Western U.S. were summarized in a paper by Patrick et al. Schumm said this paper had shown sediment yields to be very low from forested areas. In cross-examination, Walch pointed out that sediment yields in Patrick's paper actually ranged from 0.01 to 5.97 tons/acre/yr, with a median of 0.165 (3/21 at 64-67, 124-128). This was higher than what Schumm had said was typical of forested areas.

To Leaf, it was inconceivable to have the same relative instream flow of about 50% annual runoff for streams which could differ in sediment yield by a factor of 6 or more. The channel maintenance flow claims therefore needed a site-specific evaluation based on sediment yields (8/1 at 110-116).

Walch attempted to go through a calculation to illustrate how much sediment would accumulate in a stream over time based on the size of the stream and the sediment yield from the watershed. His example gave a sediment depth of 1.5 feet in 100 years, which he said would mean 15 feet in 1000 years or 150 feet in 10,000 years. Leaf said this was a biased calculation, and in the long-term some factors would be self-mitigating; therefore, it was not reasonable to talk about in-filling rates over several thousand years (8/2 at 118-132).

SEDIMENT TRANSPORT ANALYSIS

Sediment transport could be described by measurement or by sediment transport equations. Both sides conducted a number of analyses, including:

- Relationships between sediment load and discharge
- Relationships between sediment sizes transported and discharge
- Computation of the total amount of sediment moved during the field season
- An "incipient motion" analysis to determine the flow needed to move a particle of a given size (e.g. D_{50}). This "critical discharge" was compared to estimates of bankfull discharge.
- Calculation of the size of material which would move at bankfull flow—the "critical size." This was compared to particle sizes in the streambed to determine whether it would adjust at bankfull flow.
- Computation of effective discharge, the discharge moving the most sediment over time.

Sediment Load-Discharge Relationships

Sedigraphs

Rosgen defined a **sedigraph** as a graph which displayed sediment concentrations against time. It could be overlaid on a hydrograph from the same stream to illustrate how the relationship between sediment and discharge changed over time.

In the Little Beaver Creek example given by Rosgen, about 50% of the sediment was bedload and 50% suspended, on average (2/8 at 113). The sedigraph (Figure 9) showed that flow and sediment load increased towards the end of May, but then in July and August sediment levels dropped off even though flows remained relatively high. Suspended loads dropped off faster than bedload. Rosgen said these types of relationships are typical, and were the basis for the concept that high flows were mainly needed early in the season

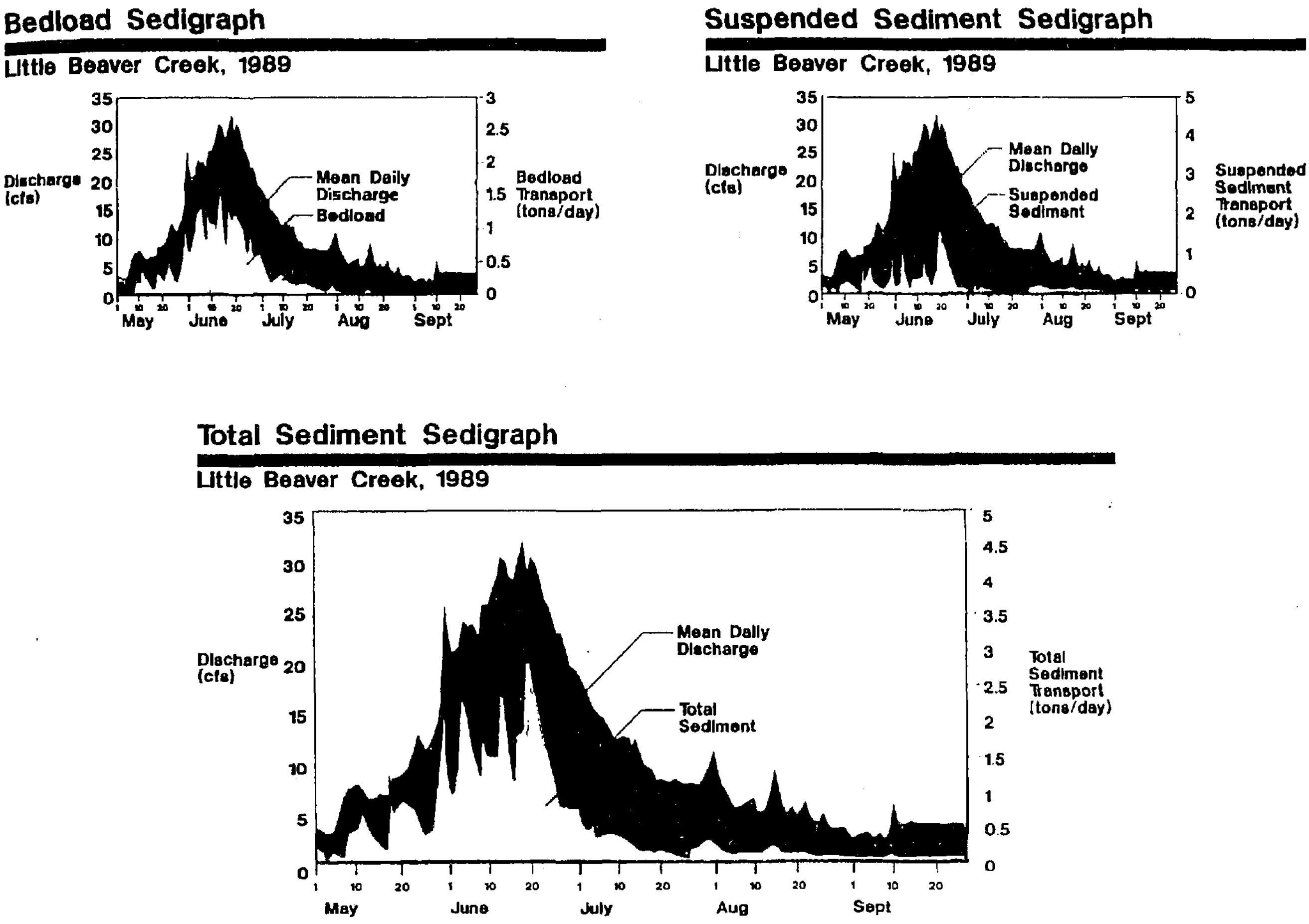


Figure 9.—Sedigraphs from Little Beaver Creek fluvial site: bedload, suspended and total sediment load. From Exhibits [A-715, 716, and 717a].

for channel maintenance. Once the larger sediment sizes and most of the sediment volume had moved, the remaining water didn't do as much work (Rosgen 2/8 at 111-112).

Sediment Rating Curves

A **sediment rating curve** was a graph which related sediment transport rate to discharge. Curves could be constructed for suspended, bedload, and total sediment load. The U.S. developed curves using measured data from the fluvial process sites. Figure 10 is a scatter plot of the sediment data collected by U.S. and opposition teams. Figure 11 shows examples of sediment rating curves, which could be plotted using arithmetic or logarithmic axes. The logarithmic axes make the relationships more linear as well as minimizing the apparent scatter. Leopold (1/24 at 57) made the point that "there is always a lot of scatter" in many hydrologic relationships like this one.

Rosgen described the term **hysteresis loop** as referring to the fact that more sediment tended to

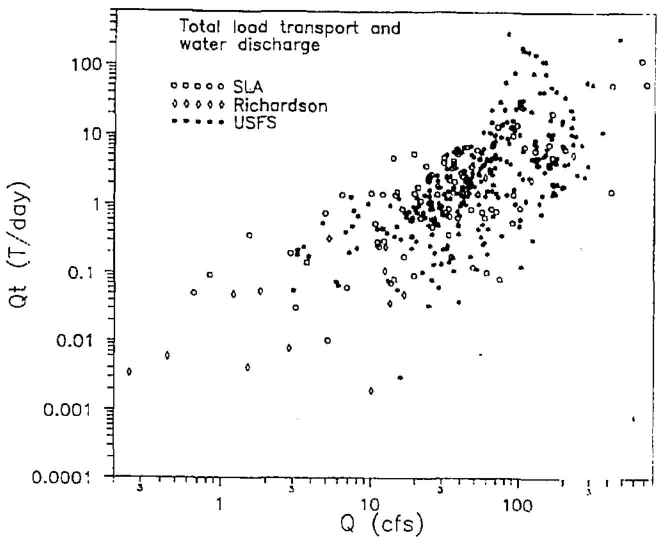


Figure 10.—Scatter plot of sediment load and discharge data measured by U.S. and opposition teams. From Exhibit [A-1084].

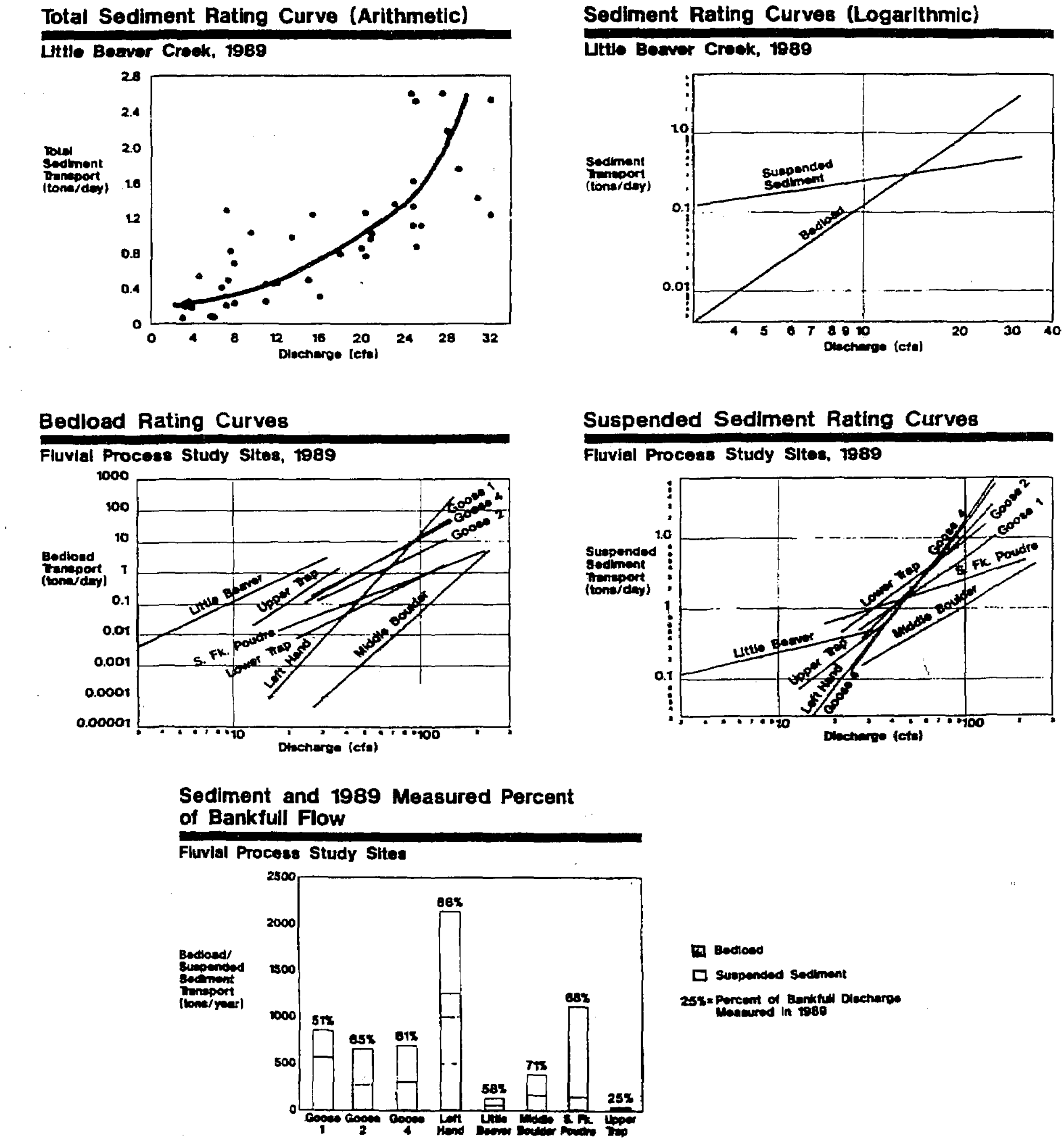


Figure 11.—Sedigraphs rating curves for U.S. fluvial sites, and total sediment transported in 1989. From Exhibits [A718c, d, 719, 720 and 721].

be transported on the rising limb of the hydrograph than on the falling limb at the same discharge rate (if a line were drawn to connect data points in the order they were sampled over the season, it would form a "loop"). In early spring, the first freshet flows carried off finer materials which were loosened during winter, e.g. by freeze-thaw processes or slumping of banks. Later in the year, this material was no longer available for transport. The amount of sediment transported and its variability therefore tended to be higher on the rising limb of the hydrograph (Rosgen 2/8 at 125-126, 138-139).

The hysteresis effect was more evident for suspended sediment because it was more controlled by supply, whereas bedload was more controlled by the available energy of the stream (Rosgen 2/8 at 127-130; Leaf 8/6 at 21-22). As particles approached the median diameter, hysteresis disappeared and transport rates became relatively similar on rising and falling limbs (Andrews 2/20 at 14-15). The R^2 for the bedload data from Little Beaver Creek was 0.73, whereas the suspended data had a R^2 between 0.3 and 0.4 (Rosgen 2/8 at 125-126, 138-139; also Schumm 3/27 at 16).

Rosgen explained that a sediment rating curve would be flat for a totally supply-limited system, meaning an increase in discharge would have little effect on sediment (2/8 at 127-130). He presented sediment data from WD1 data sets representing about 83% of the stream miles in WD1 (based on stream type). All of it showed an increase in sediment loads with discharge, indicating that the streams were hydraulically-controlled (2/8 at 116-123, 143-145). If the streams were supply-limited, the rating curves would be expected to go horizontal at some point, but none of the sediment data for WD1 streams showed this trend (Leopold 1/24 at 80-81).

Schumm did agree that the U.S.'s graphs demonstrated increasing sediment transport with increasing discharge. However, he said the Forest Service's data was inadequate and had not been collected over a sufficient time period or at sufficiently high flows to say whether or not the streams were truly hydraulically-controlled (3/22 at 115-120). He also cited a study done by Leopold on a tributary of the Cache la Poudre River to show that approximately 70% of the sediment, which was sand-sized, was moved during the rising stage and 30% on the falling stage, demonstrating hysteresis (3/26 at 163-165; 3/27 at 14-15).

Leaf argued that a sediment rating curve was only an empirical relationship and did not indicate whether a stream was hydraulically controlled or not. He also implied that there were bounds to the sediment-discharge relationship in subalpine watersheds. He and Mussetter gave the following reasons why a supply-limited stream might not have a horizontal slope:

- If sediment had accumulated in pools during a low year, then a high flow year could result in higher amounts of sediment transport.
- When streamflows increased, finer particles higher up on the streambanks could be eroded,
- Higher discharges could be associated with greater amounts of surface water and sediment (particularly suspended) entering the channel (Leaf 8/6 at 31-38, 45-50; Mussetter 6/12 at 162-164).

Quantity of Sediment Transported

The U.S.'s Analysis

Figure 11 contains a summary histogram of the total amount of sediment transported at the fluvial study sites during the 1989 field season. Percentages given are the percent of bankfull flow reached during the season (Rosgen 2/8 at 134-135). Rosgen said the results demonstrated that sediment transport did occur in the WD1 streams. For example, at Goose Creek #2, a C1 type stream, 250 tons of bedload and 600 tons of suspended load were measured over the field season (Rosgen 2/9 at 65).

The Opposition's Analysis

Richardson said the data collected by his team and by SLA indicated very low sediment discharge rates in the WD1 streams—on the order of 10 tons per day or less (7/25 at 90-94). Schumm made the comment that Jefferson Creek was almost waist-deep and near bankfull depth at the time the State's team did their studies, and there was no bed sediment moving (3/22 at 34). Simons also reviewed Andrews' exhibits and estimated the concentrations as 1.3 ppm for one site and 28 ppm for another. He said this was "basically clear water" (4/11 at 104-106).

The State's bedload concentrations exceeded 100 ppm in a few instances, but the bulk of the concentrations were on the order of 25-50 ppm except for Left Hand Creek. A short-term high bedload concentration on this stream was attributed by Rosgen to a fire in one of the small tributary watersheds (Mussetter 6/20 at 56-57, 60-64).

Harvey said for USGS data in "typical sand bed streams," it was common to see concentrations from 1000-10,000 ppm even during normal flows, and up to 100,000 ppm during flood stage (6/20 at 65). In court, he showed a few bottles with sediment concentrations of 1000 ppm, 100 ppm and 10 ppm to illustrate that only a few grains of sand were required to achieve these concentrations. Simons (4/11 at 59) said he had personally measured a concentration of 500,000 ppm on the Rio Puerco in New Mexico.

One ppm in one cubic foot per second of water was equivalent to approximately 1 ton per year (Simons 4/12 at 5). At Walch's direction, Simons applied a specific gravity of 2.65 to calculate that even the low concentrations measured at the Little Beaver Creek site would transport some 26,000 tons per year of sediment (4/12 at 8).

The Concept of Incipient Motion

Sediment transport equations typically contained an expression of the form:

(force causing the sediment to be transported) - (force required to initiate motion),

where the forces could be expressed in terms of shear stress, velocity, stream power, discharge or other units (Simons 4/11 at 60-61). Simons said a large number of sediment transport equations were based on laboratory flume experiments, with some supplemented by field data. However, the data base was generally "quite restricting" (4/11 at 63-64).

Both sides used equations which were based on **shear stress**, defined as a force per unit area acting parallel to the streambed surface. A typical unit was pounds/ft^2. Simons described it as being "like rubbing a razor over a piece of paper or like the water rubbing over the channel" (4/11 at 69).

The larger the shear stress, the more sediment which would move—depending on its availability. A certain amount of shear stress was needed before a particle of a given size would move, called the **critical shear stress**. This point at which an individual particle was just on the verge of motion was termed **incipient motion**. For a whole streambed, this was more of an average condition because turbulence might lift a particle of a certain size at one location but not another. Because incipient motion was difficult to observe, sediment transport was often measured at increasing discharges and extrapolated back to zero to determine the point of incipient motion (Simons 4/11 at 65-69, 98-108, 113-114; Mussetter 6/12 at 88).

Andrews explained that some methods for calculating incipient motion involved balancing these forces (2/14 at 59-60):

- fluid forces: the forces exerted by the stream on the particle, including,
  lift - if a surface was curved, lift was created as the fluid accelerated over the object;
  drag - created by the difference in pressure on the upstream and downstream sides of an object.
  (Both lift and drag increased with fluid velocity, and it was the combination of both forces which would move a particle out of the streambed.)
- gravitational force: equal to the submersed weight of the particle; it tended to keep the particle at rest.

When the fluid forces exceeded the gravitational force, the particle would begin to move.

Incipient motion could also be computed by comparing the shear stress on the channel boundary to the critical shear stress needed to move an individual particle. Critical shear for a particle of a given size was often calculated using a parameter called the **dimensionless shear stress** or **Shields parameter**, which was a dimensionless ratio of shear stress to gravitational force (Andrews 2/14 at 60-61).

Even though a rock might weigh two pounds, two pounds of "push" wasn't needed to make it move. For any individual particle, the beginning of motion depended on its position in the streambed; if it protruded into the flow and exposed more area, it would move more easily. If it was surrounded by larger particles, then it had a "big hill" to climb over to get out. Therefore, as flows increased, a particular particle size might start moving from one location, but the same size wouldn't move at another location until flows were much greater (Andrews 2/14 at 61-64).

The U.S. experts argued that their approach took this "hiding factor" into account, whereas the opposition had used methods developed from more uniform materials and those methods were not applicable to the WD1 mountain streams (11/13 at 147-148).

Calculation of Boundary Shear Stress

The U.S.'s Approach

Andrews used the following equation to compute boundary shear stress:

$\tau = \gamma$ **RS**, **with** τ **= shear stress,**
γ **= unit weight of water,**
R = hydraulic radius,
S = stream slope

It represented the shear stress created by the weight of the entire water column acting in the direction of the streambed slope. Andrews said this was a standard method of computing boundary shear stress in gravel bed rivers and had been used by other researchers for mountain streams (12/10 at 121-127).

Opposition witnesses argued that in the upland streams, much of the energy was actually lost to turbulence due to rough streambed conditions. The expression γRS also relied on averages, whereas sediment transport would be controlled by the "minimum energy areas" in the streams, e.g. beaver dams and the pools in step-pool systems. They therefore believed symbol γRS would overestimate the amount of shear stress acting on the channel boundary in the mountain streams (Simons 4/11 at 115-119, 146-147; Li 6/7 at 122-124; Mussetter 6/12 at 83-86). Based on the State's data, Richardson calculated that symbol γRS gave values 2-25 times larger than the shear stress actually acting on the streambed (7/26 at 52-56; 8/7 at 21-22).

Richardson also said "S" should have been calculated as the slope of the energy grade line, but Andrews had used water surface slope (7/26 at 52-56). It also came out during the case that Dawdy, Andrews and the Forest Service all gave different slopes for the fluvial sites. Andrews said the USFS values were measured over very long channel reaches. Because sediment transport measurements were taken at a specific cross-section, Andrews had used a local slope near that section to calculate shear stress. He said that in all but one case, his and Dawdy's slopes were equal to or less than the USFS values, which would make the calculated shear stresses lower (Andrews 12/10 at 129-131).

The opposition did believe the symbol γRS method would be appropriate in larger streams with width:depth ratios greater than 10 and with smaller streambed particle sizes (Mussetter 6/12 at 89-96, 122-124, 133-134). Walch countered by saying that the width:depth ratios were actually greater than 10 at most of the quantification points (8/7 at 20).

The Opposition's Approach

The opposition believed the Darcy-Weisbach equation was more appropriate for mountain streams because it accounted for the amount of energy taken up by friction and the fact that deeper water might actually be slower due to a backwater effect. The symbol γRS method would not show this. The Darcy-Weisbach equation for shear stress was given by Richardson (7/25 at 85-89) as:

$$\tau = 1/8\ (f\rho\ ^{2}),$$

with ρ **= density of water,**
= velocity, and
f = the Darcy-Weisbach friction factor representing grain resistance.

Velocity was calculated using a flow resistance equation developed by Mussetter (see Section 7). The Darcy-Weisbach friction factor was calculated using an equation developed by Hey for gravel bed streams (ASCE Journal Hydraulics Div., April 1979) (Mussetter 6/12 at 89-96, 122-124, 133-134; 6/20 at 27):

$$\sqrt{8/f} = 6.25 + 5.75 \log(\text{mean depth}/(3.5 * D_{84}))$$

Hey and another researcher, Keulegan, calibrated the 3.5 factor using field data. Limerinos had used 3.25, and the Leopold equation used by the Forest Service had a factor of about 3.9 (Dawdy 11/13 at 132-137).

Mussetter pointed out that this was a different method than what had been used for calculating values in the SLA report. The State was no longer using those values, which had been developed using the Keulegan equation. Mussetter believed the Keulegan equation had underestimated shear stress (6/12 at 108). Richardson (8/7 at 12-13), mentioned that Keulegan had just passed away that spring at the age of 99, still working for the Corps of Engineers. Keulegan's friction factor was also based on a logarithmic velocity distribution equation.

Dawdy later implied that Mussetter had selected a new equation because SLA's field data showed that the bedload sizes at a number of sites were larger than what their initial analysis said would move (11/13 at 138-143). He also demonstrated that in some cases, the Hey equation gave "ridiculous results" and would predict bigger particles moving at smaller flows. He gave an example from one site where they had predicted that a 7 foot boulder would move at a discharge of only 11 cfs. When the R/D_{84} value was less than one (i.e. rocks were no longer submerged), this went beyond the range where the equation was calibrated and it was invalid (11/13 at 143-147; 11/14 at 16-22).

Walch pointed out that both Mussetter's equation for velocity and the Darcy-Weisbach friction factor were based on a measurement of the D_{84} of the bed material. Walch said the U.S. experts had not been able to reproduce SLA's streambed size distributions from their Wolman pebble counts because some had been adjusted and some averaged. It came out during the trial that some of the Wolman pebble counts used by SLA and Richardson had been "adjusted." Richardson explained that this had been done because the Wolman counts tended to miss the large boulders and cobbles in the channel. Field crews had visually estimated percentages of large boulders, pebbles, fine gravels, etc. If the estimates showed that the channel contained much coarser material than what was sampled, the counts were adjusted upwards.

For example, at one site the Wolman count for D_{50} was 70 mm and the adjusted value 120; the D_{84} value changed from 245 to 460. At the South St. Vrain site, the D_{84} was adjusted from 200 mm to over 1000 mm. Counts were adjusted at 4 of SLA's 48 sites (Richardson 7/26 at 138-148; 8/7 at 38-47; Dawdy 11/13 at 113-117). Angel later pointed out that the Forest Service had obtained a D_{84} of 700 mm for the South St. Vrain site from their Wolman counts (11/14 at 64-72).

Dawdy said the addition of the very large particle sizes was inappropriate because they weren't part of the bed material which was being moved; in fact, a channel would adjust around their presence. They acted more like "islands" than bed roughness, and shouldn't have been included in flow resistance equations. Dawdy believed the material had to be covered by water to constitute bed roughness. He argued that the "upward adjusted" values would have caused SLA to underestimate velocities, shear stress, and the quantity of bedload which would move (11/13 at 113-118, 130-132). Richardson agreed that an error in the velocity term would be compounded in the Darcy-Weisbach equation when the term was squared (7/25 at 105-111; 8/7 at 17).

Dimensionless Critical Shear Stress

The dimensionless critical shear stress, also called the "Shields parameter" was the ratio of:

- fluid forces acting on the particle, and
- gravitational and other forces resisting particle movement.

It was related to the positions of rocks, based on an average condition. Lower values would indicate that less force was required to move the particle. A value of 0.03, for example, would mean that the fluid forces required to initiate motion of the particle were about 3% of the particle's weight. Values recommended in the literature ranged from 0.03 to 0.06. In Mussetter's experience, the most commonly used value in engineering practice was 0.047 (6/12 at 97-98). The U.S. used a value of 0.03.

Richardson said Shields had originally obtained 0.06, but Gessler had later obtained a value of 0.047 after accounting for bed forms and roughness. In flume studies, Richardson found values as low as 0.02 for isolated 3"-4" particles sitting on a "filter blanket." This was done to simulate riprap. Richardson had made the recommendation to the Corps of Engineers and Bureau of Public Roads to use 0.03 as a safety factor when designing riprap. However, he thought 0.047 was more appropriate for the WD1 streams with interlocking large particles (7/25 at 93, 97-105; 7/26 at 52-56).

Opposition experts believed a value of 0.03 represented a situation where particles were loose (e.g. in flumes) or sitting on top of the streambed. Imbrication, embedding and the sheltering of smaller particles by larger ones would mean a larger shear stress was needed to move them. Mussetter said the U.S.'s analysis using 0.03 would only demonstrate whether particles could be rolled down the channel or not. He said he had "no trouble believing" that a particle on the surface of the bed could be moved by the U.S.'s bankfull flows. This was equivalent to the painted rock studies in which particles were found to move. However it was unrelated to movement of streambed particles (Mussetter (6/12 at 99-104, 120-121; Richardson 8/6 at 144-145, 148-153).

Andrews cited numerous papers supporting the use of the 0.03 value, including the original work of Meyer-Peter, Muller and Hans Einstein (son of Albert Einstein). They were studying a reach of the Rhone River in Switzerland which had a gravel bed. A large flume was constructed using material from the Rhone River itself. The average particle diameter was 28 mm—well into the range of gravel sizes. From the flume studies, they found that in a bed of uniform-sized material, the first particles would begin to move when the dimensionless shear stress reached 0.03 (2/14 at 65-67). In 1979, Professor Gary Parker from the University of Minnesota also concluded that the 0.03 dimensionless shear stress value was appropriate. Andrews' own work in the early 1980's also agreed, as did a paper by Weinberg and Smith in 1989. Andrews said the 0.03 value wasn't for particles laying on a plane surface, but the "average-sized particles" in "relatively shallow pockets" which "are most easily moved" (2/14 at 70-73).

Andrews developed the graphs shown in Figure 12 which compared the data and dimensionless shear stresses developed by Meyer-Peter, Muller, Einstein and Parker. The data agreed well in the range where they overlapped. Some particles moved at critical stresses as low as 0.015-0.02 (2/14 at 96-102). Angel later referred to a paper by Parker which contained a statement by Andrews that the pavement couldn't adjust to equalize the mobility of very rare, large grains of approximately 5 times the D_{50}. For these, critical shear approached an asymptotic value near 0.02 (11/14 at 111-120).

Sediment Transport Equations

Once the critical shear stress was exceeded, the amount of sediment in motion could be calculated from equations based on hydraulic variables. Andrews said that certain factors were not well-known, so all equations relied "to some degree upon either measured transport rates in rivers to verify and set particular values, or flume data." He said a large number of sediment transport equations existed, and the conditions under which they were derived must be known in order to determine their range of applicability (2/14 at 89-90).

Andrews went through the history of sediment transport equations, summarized as follows (2/14 at 70-73, 91-95, 102-108):

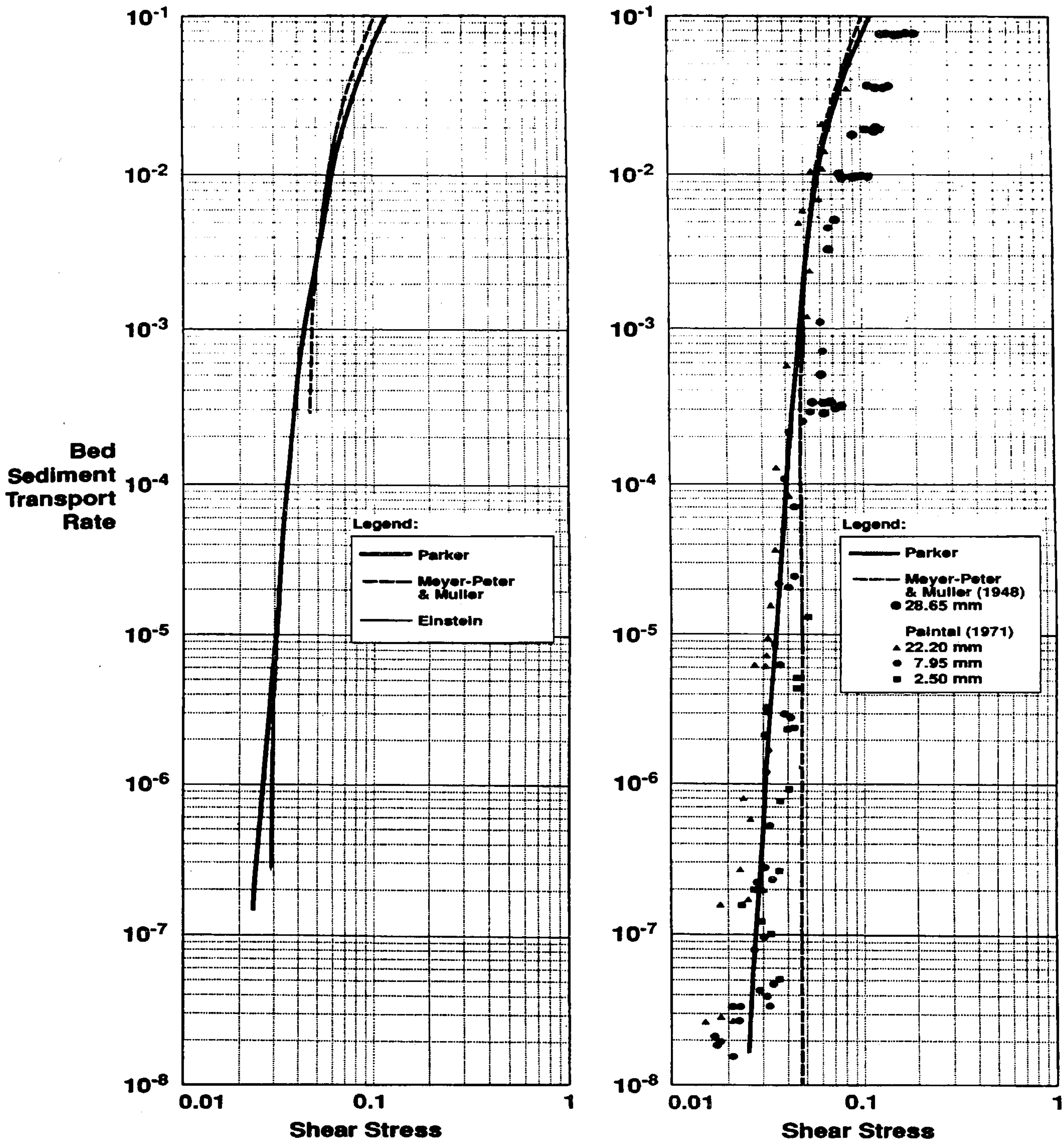


Figure 12.—Dimensionless critical shear stress values. From Exhibit [A-899].

- **DuBois**: developed an equation in 1870-80 which was based on theoretical processes.
- **G.K. Gilbert:** conducted one of the first major experiments on gravel motion at U.C. Berkeley in 1911-1914. He had been asked by the USGS director to investigate the effects of hydraulic mining in the Sierra Nevadas, which had resulted in hundreds of millions of tons of sediment being transported downstream. This had filled channels into the Sacramento Valley, causing severe flooding.
- **Meyer-Peter, Muller and Einstein:** began studies on the Rhone River about 1930. Simons (4/12 at 59) mentioned that Meyer-Peter was one person and "Muller helped him straighten out his mistakes." The Meyer-Peter-Muller formula, which used a dimensionless critical shear stress of 0.047, was published in English in 1948. Andrews emphasized that the MPM equation applied specifically to the median diameter of particles, not to individual size fractions, because it was developed using flume data with uniform bed materials.

  Einstein was actually a graduate student under Meyer-Peter. He published one of the most important papers on sediment transport in 1950.
- **Parker:** primarily used data from two rivers to develop a sediment transport equation—Oak Creek in central Oregon and Elkhorn River in Alberta. He was presently working at the University of Minnesota which had a hydraulic facility in an old Pillsbury Mill on an island in the middle of the Mississippi River. To conduct flume studies, the river water could be diverted through floodgates into the laboratory. His sediment transport equation was applicable for critical shear stresses down to 0.03.

The U.S.'s Approach

The U.S. used the Parker equation in their analysis, which was based on the concept of "equal mobility." Dawdy (11/13 at 147-148) explained that in a mixture of particles, the larger particles hid the smaller ones, and therefore it took more shear to move those smaller particles. The larger particles were more exposed to the flow and would move at a lower shear than would be expected. Therefore all the particles essentially started moving together—they were "equally mobile." All of the particle sizes would therefore move at some critical shear value. This was assumed to be the critical shear for the D_{50} sized particle in Andrews' analysis.

Dawdy went on to explain that the purpose of the pavement was to regulate how much material would move. It determined the *ability* of the particles to move and controlled the hydraulics of the system; but the *supply* of material was in the subpavement. He had done some more detailed calculations using the Parker equation, which he said actually included a parameter which varied the shear among particle sizes. The parameter (with a value of -0.982) was very close to a condition where all sizes moved at the same shear. Dawdy called this "relative mobility" rather than "equal mobility" (11/14 at 38-47, 50, 98).

In a Shields-type approach, critical shear for each particle size or range of sizes was calculated. Critical shear increased with discharge; i.e. larger particles moved at larger discharges. Using SLA's data, Dawdy pointed out that at one site, the smallest discharge actually coincided with the coarsest bedload sample. Data from other sites showed essentially no correlation of bedload size with discharge. If Shield's theory applied, there should have been a relationship. Dawdy said this data supported the fact that Parker's concepts were applicable for the mountain streams (11/13 at 148-154).

Andrews compared bedload transport computed by the Parker relationship against actual bedload transport rates measured using a Helley-Smith or other sampler. For Sagehen Creek in the Sierra Nevadas of California and 7 USFS fluvial sites in WD1, the data showed some scatter but no bias, i.e. a tendency to over- or under-estimate. Examples from two fluvial sites and Sagehen Creek are shown in Figure 13.

Andrews concluded that there was "quite good agreement" between measured bedload transport rates and those computed using the Parker formula. He said the good agreement indicated that the mountain streams were hydraulically-controlled. The scatter in the data was also comparable to what would be expected from good flume data, with most data points within approximately a factor of 2 about the predicted=measured line (2/14 at 112-115; 12/10 at 120-121).

Angel brought out that the only stream sites in WD1 where Andrews had compared predicted and measured sediment transport rates using the Parker equation were the 7 USFS fluvial sites. She said Leopold had admitted that these sites underrepresented some stream types found at the quantification points, with which Andrews agreed (12/11 at 38-41).

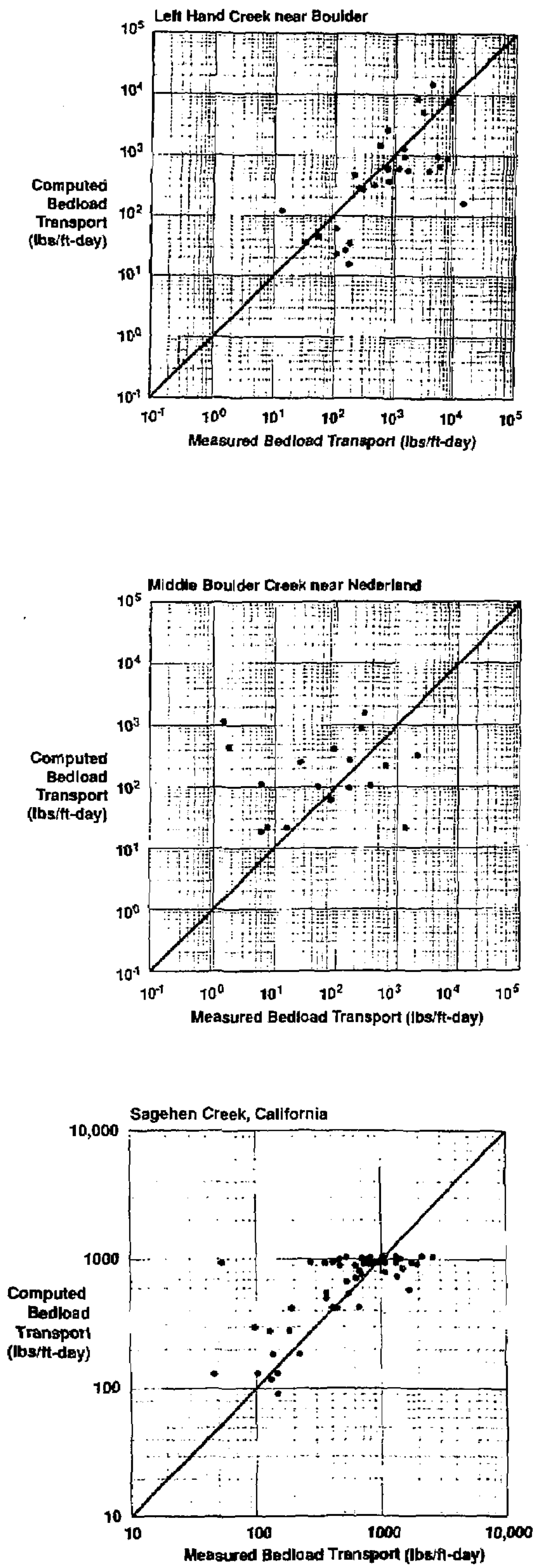


Figure 13.—Bedload transport rates computed with the Parker equation vs. measured values. From Exhibits [A-857, 873 and 876].

Mussetter discussed the sensitivity of the Parker equation, saying that very slight changes in hydraulic radius, channel gradient or the size of the material could have a very large effect on the calculated transport rate. In the Parker equation, the sediment transport was proportional to the 4.5 power of the difference between actual and critical shear stress; therefore a small change in either of those parameters could cause a large change in the result (6/20 at 90-91).

Mussetter had performed a sensitivity analysis using data from Little Beaver Creek in WD1. Andrews had initially calculated a mean annual load of about 100 metric tons per year for this site, but by the time of the trial it had gone up to 300. Mussetter found that the stream gradient had been changed from 1.62 to 1.74 percent, and that was enough to increase the annual bedload transport by a factor of three. By varying the stream gradient from 1.5% to 2.5%, the mean annual load would increase from 30-40 metric tons per year to over 10,000 metric tons per year. Mussetter did not know how Andrews had obtained the gradient (6/20 at 91-95). Walch said Andrews had used a local gradient, which was less than the average reach slope at 4 of the sites, and the same at 3 sites (6/21 at 92-94).

Mussetter concluded that he didn't have a lot of confidence in the sediment loads computed using the Parker equation because "you could come up with virtually any number you wanted by just tweaking any of the input parameters involving the shear stress" (6/20 at 97).

The Opposition's Approach

The opposition used the Meyer-Peter Muller (MPM) equation for computing bedload transport. It was commonly used in engineering analysis. Mussetter pointed out that Andrews had even used it in a 1980 paper for evaluating effective discharge (6/25 at 32). The opposition had also used the Einstein equation to calculate how much of the finer material might be carried in suspension. Results of the suspended load analysis were not discussed in detail by the opposition; in fact, Simons didn't know if the sediment transport capacity listed in the SLA report was for bedload or total load (4/12 at 64).

Like the Parker equation, the MPM equation was based on "excess shear stress." It used a dimensionless critical shear value of 0.047. In the original paper describing the MPM equation, the authors had recommended that total shear stress (γRS) should be utilized. However, the paper also discussed adjusting for the effect of riffles in the streambed, which reduced shear stress. This is what SLA attempted to do by using a different shear stress equation (Mussetter 6/21 at 143-145).

Mussetter said the hiding factor contained in Parker's equation was relatively insignificant for the purposes of calculating a stream's capacity for transporting the sizes of materials which had been captured in a Helley-Smith sampler. For predicting when critical shear stress would be exceeded, it would be important (6/21 at 138-142). However, the State's analysis of incipient motion had been based on a Shields-type parameter and did not take into account a hiding factor.

Simons pointed out that the shear stress required for incipient motion would be less if the 0.03 value were used instead of 0.047. However, that was only for the beginning of motion. When discharges approached bankfull, transport rates calculated using the two values essentially converged—and this was the range of forces which would adjust the channel, not those at the beginning of motion. Therefore the different values would not affect the quantity of sediment transported (4/11 at 110-112; 4/12 at 61).

Walch submitted a book authored by Simons which contained a discussion of when and where the MPM formula was applicable. It said that when slopes exceeded 0.001 and when bed materials were very coarse, large discrepancies between computed and observed values could occur. Li disagreed with these statements because the MPM equation had been developed using data from gravel-bed streams. He also believed Simons had recognized the mistake in his book (6/7 at 116-122, 144-145).

Andrews argued that the Parker equation worked better at low transport rates, which was the situation in the WD1 mountain streams. Using data by Paintal, which he said was regarded as the best low transport rate data available, he demonstrated that the Parker equation fit this data very well, but the MPM equation didn't. At higher transport rates, both relationships agreed with the data (12/10 at 103-107).

Using Sagehen Creek data, Andrews demonstrated that the MPM equation gave zero transport even though measured transport rates were as high as 2000 pounds/foot of channel width/day. For the majority of the USFS fluvial sites the MPM equation also predicted zero transport. The boundary shear stress exceed 0.047 on only two occasions; for one, the MPM equation predicted measured sediment transport very well, but for the other, it greatly over-predicted it. Measured transport rates at the fluvial sites were as high as 15,000 pounds/foot of channel width per day in a channel 20-25 feet wide (2/14 at 116-117). Andrews therefore believed that the Parker relationship was more appropriate for the Colorado mountain streams, particularly where shear stresses were less than 0.047 (2/14 at 117). He said SLA had used the MPM formula even though it was not applicable below 0.047 (2/14 at 100).

Incipient Motion Analysis

The U.S.'s Results

Andrews had conducted a study on 24 gravel bed rivers in the mountains of Colorado which was published in 1984. He found that in all cases, the D_{50} sized particle in the streambed "would begin to move at flows of bankfull or in most cases somewhat less." In some cases, the bankfull shear stress was almost twice the critical value (2/14 at 74).

A similar analysis was done for seven of the USFS fluvial study sites and the 244 quantification points. Results are shown in Figure 14. Andrews said bankfull shear stress and critical shear stress were calculated from measured data, including hydraulic radius, slope, the D_{50} streambed particle size and a dimensionless shear stress value of 0.03 "more or less" (2/14 at 83).

More details on the procedures used by Andrews came out in cross-examination. He had used the Limerinos equation to develop depth-discharge relationships for most sites in order to evaluate shear stress at different flow levels. At one fluvial site, a stage-discharge relationship developed from field data was used (2/20 at 97-106). For the quantification points, he had used a constant average slope of 1.5% for calculating bankfull shear stress at all 244 sites.

He justified this by saying a sensitivity analysis had been run and slope did not bias the results (2/20 at 84-86).

Andrews' results were as follows:

- *Fluvial sites:*

  Calculations showed that bankfull shear stress exceeded critical shear stress for all seven fluvial sites. Andrews demonstrated that a particle of approximately the median diameter had been collected in bedload samples on 11 occasions. Therefore the critical condition was reached at these sites even though associated flows were only 50-86% of bankfull. Average shear stress for the 11 particles was 0.031 and ranged from 0.025-0.034 (2/14 at 82).

- *Quantification points:*

  At the majority of sites, the condition for initiating particle motion was equaled or

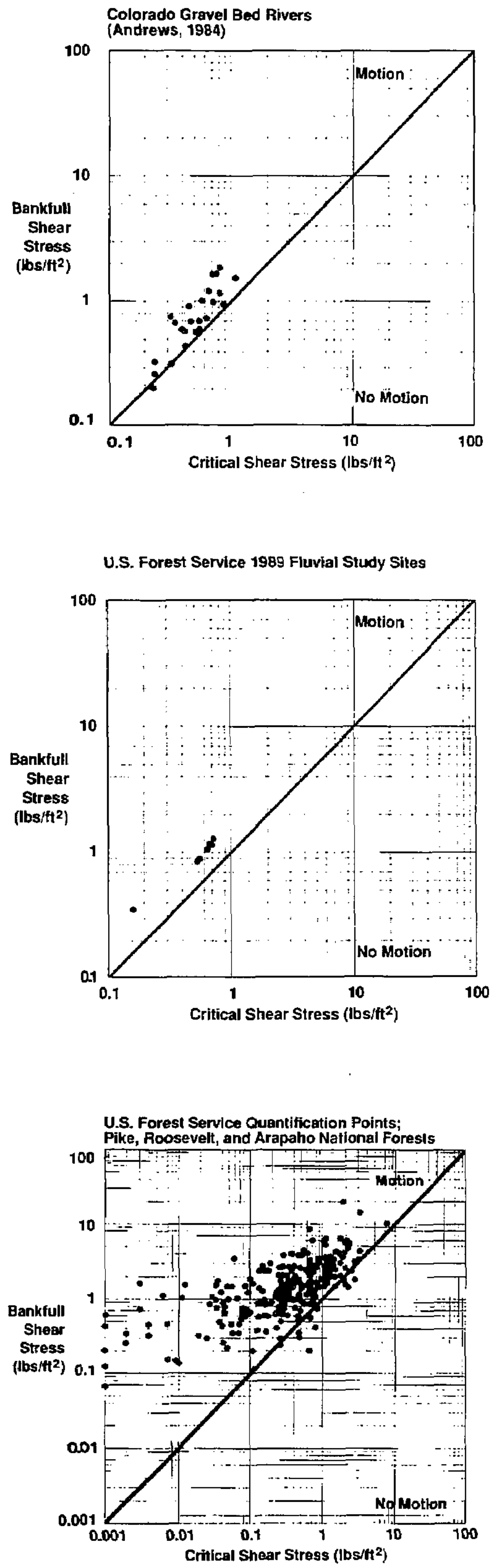


Figure 14.—Graphs of bankfull shear stress vs. critical shear stress calculated by Andrews for several data sets. From Exhibits [A-854, 855a, b].

exceeded at bankfull flow, with a few sites close to the bankfull=critical shear stress line. Only seven were below the line, meaning the D_{50} particle would not move at bankfull flow (2/14 at 75-76).

In summary, Andrews said that for most of the WD1 quantification points, the average size of material making up the channel boundary would begin to move at flows somewhat less than bankfull (2/14 at 79, 82, 133-134). He therefore disagreed with the opposition's statement that the channel boundaries would not move at bankfull flows.

Opposition Comments on the U.S.'s Analysis

- Andrews' analysis methods were questionable: Because Andrews had used the symbol γRS method and a dimensionless critical shear stress of 0.03, his analysis would indicate that particles moved at lower discharges than they did in reality (Mussetter 6/12 at 131-132). During a field trip to the South St. Vrain site, Mussetter had criticized Andrews' results which showed that a D_{50} of about 8 inches would move at bankfull flows of 30 cfs. Because of large immobile boulders at the site and their effect on velocity, he didn't think this would occur. Andrews defended his analysis and said if 8″ rocks were sitting where they were relatively exposed to the flow, they would move. The flow was about 25 cfs during the field trip and Andrews said it was difficult to see what was actually moving because of air entrainment (12/11 at 82-88).
- Movement of the D_{50} didn't necessarily indicate adjustment of the streambed: The U.S. had assumed that if there was sufficient energy to move the median size, then the whole bed was reaching a condition of incipient motion. Mussetter's calculations showed that if 0.03 was used rather than 0.047, some of the sites might reach incipient motion of the D_{50} just at bankfull. He believed some movement of isolated grains might occur even below the 0.03 value, but in order to have adjustability of the channel it was necessary to move more than just isolated particles (Mussetter 6/12 at 102, 110; Simons 4/11 at 125).

Angel presented a technical argument about whether a channel would begin to adjust at bankfull if the D_{84} was much greater than the mean water depth at bankfull. At one quantification point, Wigwam Creek, the D_{50} was about 4 inches and the D_{84} was 24 inches. At bankfull, the mean water depth was only about 14 inches and the mean velocity about 2 ft/sec. She implied that the D_{50} particles might be hidden by the larger ones which appeared to be larger than the water depth. At another site, the D_{50} itself was greater than the bankfull mean depth.

Andrews pointed out that the latter stream reach was very steep, at almost 20% slope. He said that at 30%, no water was needed at all to move rocks because they'd roll downhill by themselves. He still believed the median diameter material would begin to move at bankfull at these two sites if the critical shear stress of 0.03 were exceeded. He said that in his analysis, it was assumed that the particles were covered by water; i.e. that larger particles were sitting in a "pocket" rather than on the highest part of the streambed (2/20 at 21-27, 31-32). Dawdy agreed the equations shouldn't be used for material larger than bankfull depth (11/14 at 64-72).

Angel also pointed out that about 1/3 of the 244 quantification points had maximum streambed particle sizes greater than 5 times the D_{50}, which Andrews didn't believe would move at "equal mobility" with the D_{50} particles (11/14 at 111-120).

Walch stated that there wasn't any disagreement between the opposition and the Forest Service that some large boulders couldn't be moved by the present flow regime. However, according to Rosgen's classification, there were other areas where most or all of the bed and bank material would move. Harvey said he hadn't heard them say this; the judge also said Andrews had testified that frequently occurring flows could move material in an armored channel, e.g.. the D_{84} (4/5 at 31-35, 55-59).

- <u>If critical shear stress wasn't reached at bankfull discharge, maintenance flows weren't needed.</u>

Trout used the example of Little Beaver Creek near Rustic to show that the sediment transport didn't really begin until about 25 cfs, yet the instream flow claim began at 10 cfs (2/20 at 9-12).

Angel asked why flows up to bankfull were claimed for the seven quantification points where bankfull flow wouldn't move the median size. Andrews' analysis had shown that significant portions of bedload might not start moving until 70-90% of bankfull flow at some sites, yet no distinction was made in the amount or duration of flow claimed for those streams. Lower flows would be insignificant in terms of sediment transport (2/20 at 9-12).

Andrews defended the methodology used for the WD1 case, saying that the data showed the median diameter particle moved even during relatively low flow years at many of the sites. He also said that it would depend on the stream; e.g.. in sand-bed channels which represented about 20% of the WD1 streams, bedload would move at very low flows. He did agree that for the 7 quantification points where critical shear stress wasn't reached at bankfull, lower flows wouldn't have an effect on sediment transport relationships (2/20 at 12). He also agreed with Trout that from the point of view of sediment transport, there really wasn't a need for a minimum flow below 25 cfs at the Little Beaver Creek site (2/20 at 87-88).

The Opposition's Results

Richardson had computed critical sediment sizes for incipient motion at the State-defined bankfull flow. Even using a critical dimensionless shear stress of 0.03, he found that not much of the streambed material would move at bankfull discharge. Critical sediment sizes varied from 38 mm to 10 mm. The largest % of bed material which would move was 55%; even in this case, Richardson believed the remaining 45% would be coarser material which would shield the smaller materials and keep them from moving (7/25 at 93, 97-105).

SLA's initial analyses using the USFS estimate of bankfull flow and a 0.047 critical shear stress indicated that much less than 50% of the material comprising the bed would be in motion at bankfull flow (Simons 4/11 at 119-121). However, Walch pointed out that at 18 of SLA's 34 sites, field crews had caught rocks larger than the critical size at flows less than bankfull. For example, at South St. Vrain, SLA's estimate was 6 mm, but they had caught a 25 mm particle at flows less than bankfull (Walch 4/12 at 49-58; Dawdy 11/13 at 138-143). Richardson defended SLA's work by saying critical stage was a statistical situation where turbulence could move some particles larger than the critical size (8/7 at 21-24).

When Mussetter re-analyzed the data using the Hey equation, it increased the estimated boundary shear stress. He used dimensionless critical shear values of 0.03 and 0.05 in his analysis. Using the 0.05 value, all of the data fell below the line where bankfull shear = critical shear for the D_{50} streambed particle. Even with the 0.03 value, the majority of sites fell below the line. Musetter also plotted the ratio of bankfull shear to critical shear against slope. In general, the flatter streams had ratios closer to one. The steeper streams would therefore be much less likely to move their bed materials (6/12 at 111-112).

Mussetter concluded, "for the majority of the sites, we are not reaching a condition where you clearly are capable of adjusting the channel bed for the range of discharges that are being claimed by the U.S." Since the bankfull discharge was not moving the streambed material, it was therefore not the channel-forming discharge for those streams as assumed in Chapter 30. He did agree that one site, North Tarryall Creek, had a meandering mountain section where critical discharge for moving bed material might be reached at U.S.-defined bankfull. It showed some signs of lateral adjustment (6/11 at 113; 6/12 at 105-107; 6/20 at 156-158; Dawdy 11/13 at 143-147).

Particle Size-Discharge Relationship

The U.S. maintained that a range of sediment sizes would move at any given discharge, but that the particle sizes transported generally increased as discharge increased. Bedload measurements at the fluvial sites showed that particles of the same sizes moved at medium and high stages, but more of the larger sizes were found at higher flows (Rosgen 2/8 at 110-111). Figure 15 shows distribution curves of bedload materials at different flow levels and bed material size distributions for the Little Beaver Creek site. At 3.2 cfs, most of the particles were 2 mm or less. The largest particle size caught was actually 65 mm, during a 30 cfs flow. The results indicated that as discharge increased, the sediment sizes transported also generally increased—even though this stream only reached 58% of bankfull flow (2/8 at 164-170).

Data for the other fluvial sites, at which peak flows averaged 30-40% of bankfull, also showed an increase in particle size with higher flows. At Left Hand Creek, the peak flow reached 75-80% of bankfull and it moved the D_{84} particle. Rosgen emphasized the fact that particles moved at flows considerably less than bankfull. He said the flows from about 30% of bankfull up to bankfull during the snowmelt season was where the bulk of the sediment yield and the largest sizes would move (2/8 at 180-181; 2/9 at 23-24; 2/12 at 91-92; 2/13 at 86-88).

Chavez described a study done at one of the fluvial sites where a hole had been excavated in a sand bar and samples of material deposited in it over the season were sampled. The sampled particle sizes were smaller than the original streambed materials. Chavez explained that this was because bankfull flows did not occur (2/5 at 104-129).

Dawdy said the Parker method could also be used to predict the size distribution of transported

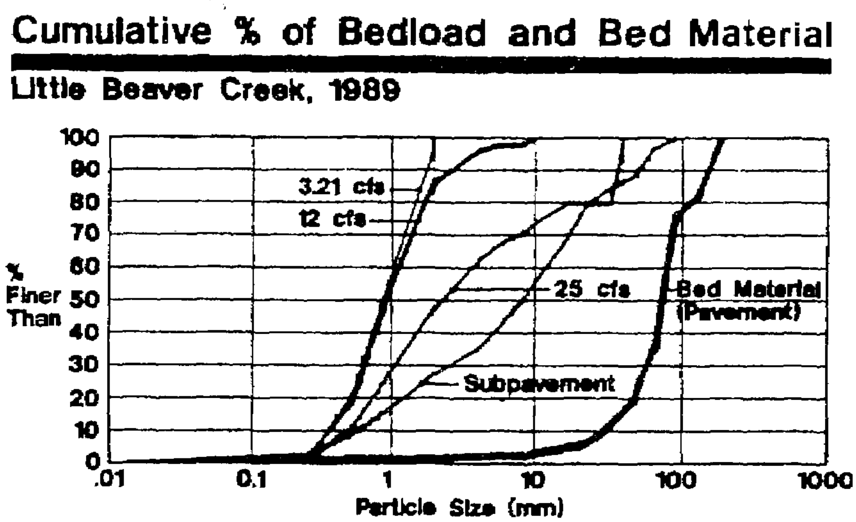


Figure 15.—Measured particle size distributions for bedload and streambed materials at Little Beaver Creek fluvial site. From Exhibit [A-723g].

bedload materials if it were calibrated to site-specific conditions. He demonstrated this using data from Coon Creek in Wyoming, a gravel-bed mountain stream with 4 years of data. After calibrating the equation with data from one year, he used it to predict results for the 3 other years. He found that he could predict particle size distribution within 11% for two years and within 35% for the other year. All of the predicted values were close to 2 mm. Dawdy explained that the Parker method wasn't used for the U.S. quantification points because it was too data-intensive (11/14 at 53-54, 108-111).

Schumm argued that the U.S.'s claim that cobbles and boulders would move through the channel at bankfull flows could be refuted "just by the simple observation that the beavers that have built dams in these valleys are not being cobbled to death" (3/21 at 153-154). Mussetter also said the sizes of particles transported by the flows at the U.S. fluvial sites were small (6/20 at 80-82).

Sizes of Particles Transported vs. Streambed Particle Size

Mussetter said one way of evaluating whether a stream was hydraulically controlled or supply-limited was to compare the sizes of streambed materials and the sizes transported. If the sizes transported were not represented in significant quantities in the bed, then the stream might be supply-limited. Einstein had suggested that for a particle to be represented in significant quantities in the bed, it had to be at least the D_{10} size, as a rough rule of thumb (6/12 at 160-162, 168-169).

Mussetter demonstrated that the sizes of sediment caught in the Helley-Smith samplers by the SLA crews were significantly smaller than the streambed materials. This was also true for the U.S. fluvial site data. He compared the largest particles caught by USFS crews using Helley-Smith and instream bedload samplers to the D_{84} bed material sizes. The sizes caught in the Helley-Smith samplers were similar to those caught in the instream sampler; sometimes the Helley-Smith sampler even caught larger particles (fig. 16). Overall, the samplers caught very few large rocks and even these were much smaller than the D_{84} sizes. For virtually all of the sites, the bulk of the bedload samples were in the sand and gravel size range. For example, at Little Beaver Creek the streambed surface had a median size of about 84 mm, but the median size of the bedload samples was 3.8 mm (he also said 1.5 mm), and the largest size caught was 45 mm (6/12 at 146, 154-159; 6/20 at 65-75, 80-82).

Parker had said that the gradation of the transported material and the subsurface materials should be similar. Mussetter said neither the State's

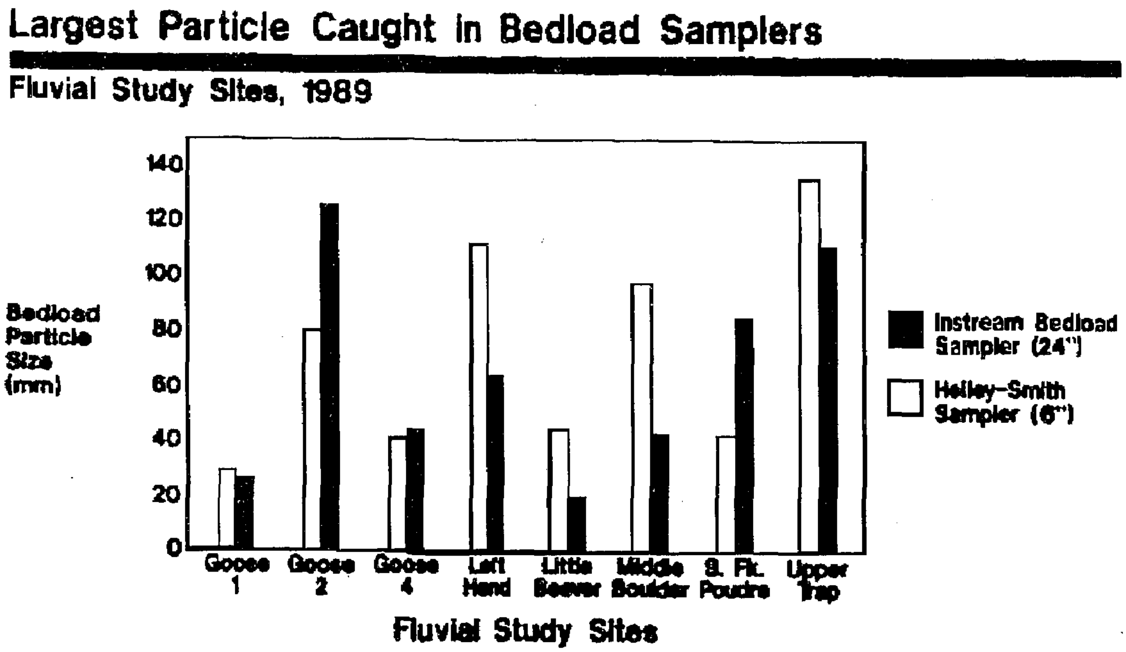


Figure 16.—Largest particle size caught in 6" Helley Smith and 24" instream bedload samplers. From Exhibit [A-725].

or the Forest Service's data supported this conclusion. The subsurface materials were significantly coarser than the transported materials. Data from Coon Creek and the East Fork of Encampment River in Wyoming showed the same trends. Leaf presented data from the Fraser Experimental Forest to demonstrate that materials captured in the weir ponds were much finer than the streambed materials (7/31 at 129-141; 8/1 at 28-30).

Because the data did not indicate that the sub-pavement material was actually moving, Mussetter concluded that it was being supplied from other sources. He said the flows measured during 1989 were not adjusting the streambed "to any significant degree." The fluvial sites were clearly supply-limited streams, and the bulk of the quantification points were probably even more so (6/20 at 80-84; 6/25 at 26-27).

Walch discussed SLA's data, demonstrating that at several sites the sediment size gradations seemed to be truncated on the upward end at 25 mm, even though that size only represented 70-80% of the materials caught in some cases. Mussetter explained that the laboratory didn't have the ability to measure the larger samples, so they discarded them. He said the sizes might not have been recorded for a few rocks larger than 25 mm. They were weighed, however, and the weights were taken into account when computing the percentages below that size (6/21 at 96-100). He said the largest particles caught by SLA in the Helley-Smith sampler were in the 40-60 mm size range. Walch asked whether they would have caught even larger particles if they had used a sampler with a larger orifice. Mussetter said it was possible, but didn't know if it was likely (6/21 at 101).

Sediment Transport Capacity

The Opposition's Analysis

The State's experts did a sediment transport analysis in order to evaluate the capability of the U.S. claimed flows to actually move the sediment supplied to the stream channels and the potential for aggradation if flows were reduced (6/12 at 137-138).

Mussetter used the MPM equation to estimate sediment transport capacity for the sizes of sediment actually measured in the streams with Helley-Smith samplers. He said this was a good approximation of the material moving in the channel and the material being supplied from the watershed. Using the MPM equation, he calculated transport capacity for each individual size range and then summed these up based on the percentage of each size range in the overall mixture of sizes caught. He used a range of discharges in his calculations, up to the SLA bankfull flow. If data were not collected at bankfull discharge, the equation was first calibrated using data collected at smaller flows and extrapolated to higher flows. For flows larger than those measured in the field, Mussetter also calculated the critical particle size using an incipient motion analysis. If larger particles could move than had been measured at lower flows, these larger sizes were included in the transport calculations (Mussetter 6/12 at 139-146; Simons 4/11 at 86-87).

In his calculations, Mussetter had actually used the median of a range of particle sizes. For the largest size, the median represented particles up to about 75-82 mm which was larger than the largest particles caught in the samplers. He argued that if the largest sizes were underrepresented, e.g. because SLA's 3" sampler wasn't large enough to capture them, that this would actually increase computed transport rates because smaller particles were more easily moved than larger ones (6/21 at 101, 105-106). His newer calculations using the Hey equation did not significantly change the transport of the D_{50} sized particles (Simons 4/11 at 122-124).

Simons showed a graph of measured and computed sediment transport for the Little Beaver Creek site. It indicated that the ability to transport sediment was much, much larger (up to 1000 times) than the actual supply. For other sites analyzed, SLA found that the ability to transport the sizes actually moving in those channels was 100-1000 times larger than the amounts measured. Simons agreed with these results because in his observations, the mountain streams remained quite clear even at high flows. On flatland streams, Simons would expect the computed and measured values to be about the same, meaning capacity and supply were approximately equal (4/11 at 132-135).

The opposition argued that because the mountain streams had a capacity for transporting sediment which greatly exceeded the supply, the sediment could be transported by reduced flows. The State had calculated flows for transporting the available sediment using a gross relationship between sediment discharge and water discharge, and an assumption that measured amounts were representative of what was delivered to the streams (Mussetter 6/19 at 58-68). However, they did not concede that these flows were needed for channel maintenance; rather it was their intent to show that the U.S. claims were based on a gross overestimation of the amount of water needed (Schumm 2/7 at 147, 155-156).

The State's "transport flows" generally amounted to less than 5% of the peak of the mean annual hydrograph for the SLA sites. For some streams, a relatively low flow of 1 to 5 cfs might be needed; for others, no flow was required. Mussetter later explained that the "zero flow" values might have been rounded off and a minor amount might actually have been required (Rosgen 2/9 at 27; Mussetter 6/19 at 62-63; 6/25 at 13-14, 16-17).

Mussetter also agreed that a more refined analysis might have given higher "maintenance" flows. The SLA report presented results of a more refined analysis which had been done at four sites. These calculations took into account the incipient motion for individual size fractions and the actual runoff measured in the stream. Mussetter concluded that this level of analysis was needed to obtain precise estimates of the flow that would transport the existing sediment supply. The analysis would require actual flow sequences, information on the operating scheme and sediment-trapping characteristics of diversions, and on sediment sources (e.g. relative quantities from tributaries, overland flow, bank erosion, and land use activities) (6/19 at 67-69).

The SLA report concluded that streams with bedrock or larger cobble and boulder bed materials (A1, A2, A2a, B1-1, B1, and C1-1):

> *"generally have sufficient energy to carry significantly more sediment than is delivered from upstream channel and watershed areas, have inadequate suitable plant growth medium to support significant vegetation encroachment, and cannot move a sufficient percentage of frequently occurring flows. For these types of streams, no channel maintenance flow is required..."*

Under this assumption, over 40% of the quantification points in WD1 would require no flow; therefore, these streams could be completely dried up (2/9 at 25-26, 69).

Leaf had also made some calculations of sediment transport using a regional sediment yield curve. He had assumed that only the bedload components required transport. As an example, for one fluvial site, Goose Creek #4, about half of the watershed was in the montane zone and half in the subalpine zone. He assumed no introduced sediment from the subalpine zone. In the montane zone he assumed 60% of the introduced sediment would be transported as bedload (based on USFS fluvial site data). He calculated an average annual sediment yield of 900-1000 tons per year, about 3 times the amount measured in 1989. By assuming that the stream was at geomorphic threshold, he estimated that only about <u>7.5% of the average annual runoff</u> would be needed to move the sediment load. He concluded that water was not needed every year to move sediment, and that bankfull and greater flows could transport the 1000 tons per year of sediment supply. His purpose in doing this calculation was to show the importance of doing a site-specific analysis. However, he said these were very preliminary calculations and did not recommend this method for quantifying channel maintenance flows (8/1 at 119-123; 8/2 at 11-16).

The U.S.'s Analysis of Sediment Transport by SLA and U.S. "Maintenance Flows"

Rosgen compared the amount of sediment actually transported at the Little Beaver Creek site with the amount carried by SLA's "sediment transport flows." Sediment transport rates at about 60% of bankfull flow were approximately 1.5 to 2 tons per day. The SLA "transport flow" would only move about 0.007 tons per day. For the entire 1989 field season, the SLA flows would have moved <u>3 tons</u> out of the 122 tons measured, <u>leaving 119</u> for potential deposition. Their "transport flow" of 1.6 cfs was less than the smallest flow at which bedload measurements were collected by the Forest Service, measured at 3.2-3.5 cfs. Those small flows gave a negligible catch of particles 2 mm and smaller (Rosgen 2/7 at 150; 2/9 at 27, 36-38).

Rosgen said the U.S. channel maintenance flows would have covered the spring runoff period in Little Beaver Creek. Since most of the bedload transport occurred during that time, the claimed flows would move essentially the same amount of bedload as natural flows. He estimated that the U.S.-claimed flows would transport <u>81.5 tons</u> of total sediment load, <u>leaving 40.5 tons</u> in the channel. However, 72% of the remaining material would be suspended sediment—mostly fine gravel and sand. It was Rosgen's opinion that this material did not have a large energy requirement for movement, and would be moved out with early freshet flows the following spring.

Rosgen said the larger bedload materials were more important for controlling the stability, morphology and maintenance of the stream. Because these took more energy to move, it was important to maintain enough flow in the channel to move the largest sizes contributed by the tributaries. He said the stability of the stream could be maintained if the majority of sediment and the largest sizes were taken care of. Suspended sediment was more easily moved so it would not create channel instability and unfavorable conditions (2/8 at 130-131; 2/9 at 12-17; 2/12 at 105-110).

The opposition argued that a diversion taking all the flow on Little Beaver Creek in excess of the 1.6 cfs SLA "transport flow" would also divert the sediment carried by it. The judge seemed to support this idea, and asked why, if the flows were reduced, wouldn't the amount of bedload transport also be reduced? Rosgen said that it would depend on the type of diversion; for example, diversions from the surface of the stream would take more suspended load than bedload. He said it was common for structures to fill with sediment, which was typically flushed back into the stream. He also explained that even if bedload movement were reduced at the diversion, tributaries would continue to bring in sediment (2/9 at 41-44).

The judge still maintained that there would be a change in the total amount of bedload moved, and that Rosgen's claim that a certain amount of the 1989 transported load would be left in the stream if only 1.6 cfs were provided was incorrect. The amount of bedload moved would be less, in the judge's opinion (2/9 at 46-51).

The opposition also picked up on Rosgen's statement that the streams could carry more sediment during the spring freshet flows. They said it supported their arguments that the WD1 streams were supply-limited and could carry more sediment than they were presently carrying. Rosgen agreed that the smaller sizes remaining would not be energy-controlled and that they would be moved at low flows (2/12 at 113-115).

In redirect, Walch asked Rosgen if the streams of WD1 were capable of carrying more sediment which might be produced from fires, or by management activities such as timber sales or road building. Rosgen said that he thought the streams could transport more sediment under certain conditions, but it would depend on the size of sediment, timing from sources, and total volume. He said increased supplies were usually associated with the suspended component. Under the U.S. claims, the streams in WD1 could still maintain their stability under the reduced flow regime because the smaller sizes remaining as a result of lower flows in summer to early spring had a lower energy requirement. It did not mean the peak flows claimed could be reduced below bankfull discharge because that would reduce the stream's ability to move the coarsest particles which controlled bed topography (2/13 at 120-125).

Andrews claimed that the sediment transport relationships were implicitly built into the quantification process because the channel with its bed materials and slope and flows would not exist "without having a very specific sediment transport rate" (2/20 at 11). He said the object of the instream flow claims was to maintain flows at and near bankfull for roughly their natural duration. There would be some years where little sediment was transported because of low flows (2/20 at 93-94). He also argued that it was difficult to predict which years would reach bankfull or when it would be reached, because it would depend on how fast the snow melted. Flows up to bankfull were claimed because conditions for moving sediment could be reached in any given year (2/10 at 13-14).

The U.S.'s Analysis of Bedload Movement at the Fluvial Sites

In the U.S. rebuttal case, Dawdy presented additional analyses to illustrate that the sediment transport concepts and analyses used by SLA were incorrect. He had estimated bedload movement for the Forest Service's fluvial sites using Parker's equation, and field data which included the D_{50} of the subpavement and a local slope at the cross-section where bedload was measured. Estimates of bedload transport by Parker's equation were compared to what was actually measured. The equation had been calibrated by Parker using data from Oak Creek in Oregon which was not a high mountain stream.

Results showed a scatter about the line of equal fit, generally with good correlation. The Parker equation tended to predict the higher bedloads fairly well. At some sites, it overpredicted the low bedload measurements, but at one site it underpredicted by about 25%. Using the Coon Creek, Wyoming data, agreement was within plus or minus 25%. Dawdy said he believed the predictions were reasonable, especially considering the fact that the equation had not been calibrated to the WD1 streams. He surmised that with proper calibration the sediment loads could have been estimated even more closely (11/13 at 161-171; 11/14 at 23-38).

Dawdy had also used a flow duration curve for the Coon Creek data along with the sediment transport estimates to show that the 18 highest flow days carried 65% of the bedload. This supported the U.S.'s contention that most of the bedload moved at high flows (11/14 at 23-38).

Angel brought out a number of errors in Dawdy's analysis. Apparently he hadn't received all of the Forest Service's data from the fluvial sites and some had been erased for at least one site. At the Left Hand site, he had only used 29 out of 49 measurements. Some zero measurements at Little Beaver Creek had been eliminated (11/14 at 8-16). Dawdy had also used different subpavement D_{50} values than those given in the fluvial process site books. At one site, the Forest Service had listed a median size of 24 mm and Dawdy had used 47.5. Angel demonstrated that about 25-30% of the individual size fractions were left off of Dawdy's plots of computed bedload sizes. Dawdy agreed that he had excluded some points from the gradations. He hadn't analyzed the effect of using different values of slope or particle size values (11/14 at 130-132, 147-149).

Angel also referred to the immense amount of scatter in one of Dawdy's sediment load-discharge relationships. A bedload of 0.1 ton per day could occur at discharges ranging from 3 to over 200 cfs (11/14 at 102-104).

Example: Sediment Transport in the Fall River After the Lawn Lake Dam Failure

Lawn Lake was located in Rocky Mountain National Park. In 1983, the dam on Lawn Lake failed and the floods released carried massive amounts of water and sediment into the Fall River. The peak discharge was about 10,000 cfs or roughly 30 times the 500-year flood (Harvey 7/13 at 27-30). Costa, a USGS researcher, demonstrated that the flood had no effect on Horseshoe Park, a lower valley through which Fall River flowed, because the valley was base-level controlled by a downstream moraine and the flood spread out over the valley. However, when the floodwaters reached more confined areas, they destroyed the existing channel and areas lateral to it. They caused millions of dollars in damage at Estes Park (Andrews 7/13 at 62-64). As a result of the flood, sediment loads of the Fall River went up by a factor of about 1000 compared to preflood levels (Harvey 4/4 at 902-904).

One of Harvey's graduate students, Pitlick, monitored sediment levels in Fall River after the dam break. At the study site, the stream was a Rosgen C-type, "mountain-meadow" stream. According to Harvey's and others' studies, the debris fan "armored up" after the first season following the dam break, but it then began to degrade from upstream to downstream as the sediment supply was cut off (4/4 at 904-908).

Harvey said the initial sediment loads caused point bars to form in the channel. According to U.S. experts, this should have caused the opposite banks to retreat. However, this did not occur. Harvey said the streambanks were root-reinforced and very strong, and the original channel bed contained heavily iron-stained cobbles which was an indication they hadn't moved. Instead of lateral migration, the stream just redistributed the deposited sands and fine gravels during high flows, which allowed the channel to re-establish itself. Harvey said he would expect the WD1 channels to respond in a similar manner if sediment loads were increased below a diversion—that the channels could accommodate them (4/4 at 908-911; 4/9 at 114-115).

Mussetter computed sediment transport capacity for the Fall River and compared it to sediment measurements taken in the area affected by the dam break. In 1983, the measured and calculated capacities were fairly consistent, but after awhile the channel began to clean itself out and the transport capacity and measured rates began to deviate. By 1985, there was a 10-fold difference, and in 1986 it was even greater—indicating that it had again become a supply-limited stream. At a site further downstream, the channel had not cleaned itself out and in 1986 it was still approximately a hydraulically-controlled stream. Mussetter said the 1983 results showed that the calculations of transport capacity using the MPM equation provided reasonable results. In the supply-limited streams in WD1, calculations couldn't be verified with actual measurements because transport was less than capacity (6/12 at 168-173; 6/19 at 32-36).

Andrews pointed out that this was the State's only comparison of measured and computed sediment transport rates using the MPM equation, and he did not think this was an appropriate comparison. When measurements were taken in 1983 after the dam break, the channel was filled with sand of sizes less than 1 mm. As a result, sediment transport rates were very high and fell into the region where the MPM equation worked well. As the sand was removed over a period of time at Fall River, the channel returned to its previous state and was more typical of mountain streams. However, Mussetter had used the same sediment size, 1mm, for all years. In reality, the sediment sizes increased from 1 mm to 10 mm. Andrews said if Mussetter had used the appropriate streambed sediment sizes, the MPM equation would have fit the data quite well and would have shown that the stream was hydraulically-controlled. He also said other data sets were available, including the USFS fluvial site data, with which the State could have tested the MPM equation (12/10 at 110-119).

Andrews said that after the dam break, the Fall River channel lost approximately 60% of its capacity due to accumulations of sand. He pointed out that it was the relatively common channel-forming flows in subsequent years which eroded this sediment and returned the channel to pre-flood conditions (12/10 at 146-147).

Angel asked Andrews where he had gotten the information about bed material sizes changing over the four years, pointing out that the D_{50} of the measured bedload sediment remained about 1 mm from 1983-1986. Andrews still maintained that the bed material had coarsened (12/11 at 41-46).

Effective Discharge

The U.S.'s Approach

Andrews described effective discharge as an index representing a range of flows which transported the majority of sediment over a period of time. The lowest flows were more common but did not carry as much sediment, whereas the highest flows carried more sediment but were relatively uncommon. Therefore, it was the flows which carried an intermediate amount of sediment and occurred relatively frequently which transported most of the sediment over time (2/14 at 119-121).

Leopold said a river would adjust its channel shape and size such that it would just carry the discharge with the largest amount of sediment load over a long period of time (1/24 at 75-76, 82). However, Andrews added that it was actually the entire range of sediment-transporting flows which built the channels. Therefore the flows transporting sediment and those forming the channel were closely related. Wolman and Miller were the first to publish the concept that effective discharge was significant geomorphically in terms of moving sediment and forming the stream channel (Andrews 2/14 at 119-124; 12/10 at 132-134).

Flow duration curves or actual flows could be combined with sediment rating curves to determine the flow which carried the most sediment. Sediment rating curves were to be developed either from measured sediment and discharge data or from sediment transport equations. Andrews (2/14 at 121-124) calculated effective discharge for the U.S. fluvial sites and two diversion sites. Effective discharge for these sites closely approximated bankfull flow. Results are shown in Figure 17.

- ***Fluvial sites:***

  Andrews used the Parker equation with USGS discharge data to develop effective discharge graphs for the USFS fluvial sites and 24 gravel-bed rivers in Colorado. The graphs indicated that it was the intermediate discharges in all cases which moved the most sediment. Some graphs had distinctive, sharp peaks whereas others were more rounded and had a broader range of discharges important for transporting sediment.

  Andrews demonstrated that the effective discharge was in fairly good agreement with bankfull discharge (fig. 17). At some sites the difference was about 20-30%; at others they were almost exactly the same. Andrews said the good agreement between effective and bankfull discharge demonstrated that the channels were adjusted to the flows moving most of the sediment. The effective discharge was the "cause" and the bankfull channel the "effect."

  He also demonstrated that the rise/recession flows to the left of bankfull discharge on the effective discharge graphs transported a substantial amount of sediment. There was a remaining fraction transported by flows larger than bankfull. He explained that "it would not be right to think that there is just one magical effective discharge. There is really a range of flows—somewhat above and below—that transports the majority of the sediment over a period of years." He estimated the range of flows as being approximately plus or minus 10-20%. Therefore the effective discharge represented a "band" of discharges that formed the stream channel (2/14 at 124-125, 130-132; 2/15 at 8-11; 12/10 at 136-138).

- *Diversion sites:*

  Andrews studied the effects of diversions on channels at two sites, one in WD1. These sites were chosen because USGS discharge records of relatively long length were available both above and below the diversions. Andrews calculated the above and below effective discharges using the Parker equation and the USGS records. Bankfull discharge was estimated using the Limerinos equation and survey information from the Forest Service. The D_{50} streambed particle size was based on Wolman pebble count data (2/15 at 36-58). Results were as follows:

  - Denver Diversion, Fraser River

    The Fraser River diversion was built about 1935. Bypass flows amounted to about 40-50% of the streamflow. Channel width decreased significantly downstream, but it was "partially maintained" by bypass flows. Andrews and Collins had observed that the bed materials in the downstream channel were noticeably finer as a result of periodic flushing of accumulated sediments from behind the diversion dam (12/10 at 150-154).

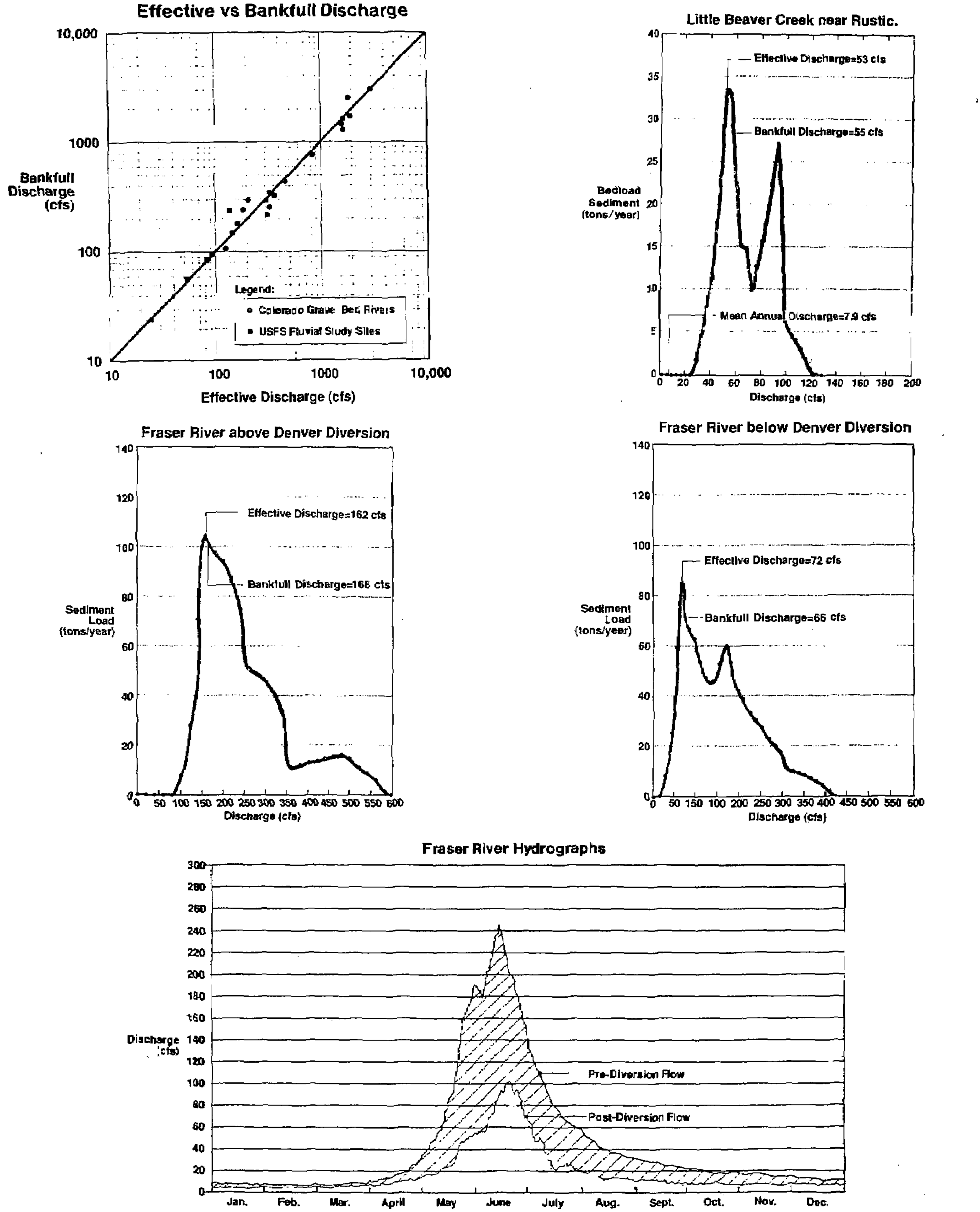


Figure 17.—Effective discharge analysis for U.S. fluvial study sites and Fraser River diversion site. From Exhibits [A-861, 869, 923 and 924].

Pre-diversion records (1911-1935) were compared to post-diversion records (1936-1988) to determine the influence of the diversion. Andrews said its effect had been to reduce peak flows by roughly 100 cfs (the amount diverted to Denver) in the range of flows which transported the most sediment. For larger flows, the effect of the diversion on flood peaks diminished, and for 100-year floods there was no difference. Andrews said this was a typical impact of diversions and flood control reservoirs. The combined effect of reducing the channel maintenance flows but not the large floods was to increase the amount of flood water outside the channel and increase velocities within it.

The effective discharge for pre-diversion data was 162 cfs which agreed well with the upstream bankfull discharge estimate. Post-diversion effective discharge was only 72 cfs, and the downstream bankfull estimate was 66 cfs, also indicating close agreement (2/15 at 12-15, 18-20).

Angel, an attorney for the State, questioned the use of pre- and post-diversion flow data, and asked Andrews whether he had looked at the differences in rainfall for those two periods. He said he had not compared precipitation records or streamflow records for those time periods but that both periods included a range of high flow and drought conditions (2/20 at 41-43).

- Left Hand Creek Diversion

The Left Hand Creek diversion had been operating for over a century. During the snowmelt runoff period, slightly more than half of the flow was diverted. A U.S. fluvial site and gaging station were located immediately upstream. Monthly diversion records were available from the State engineer for average monthly diversion flows. These were subtracted from upstream gaged records to construct a downstream hydrograph with a monthly time interval. The downstream site was actually about 10% steeper than upstream.

Upstream of the diversion, effective discharge was approximately 160 cfs and bankfull discharge at the fluvial site was estimated at 174 cfs. Downstream, the effective discharge was 100 cfs and the bankfull discharge 102 cfs (2/15 at 20-24).

In cross-examination, Trout pointed out that the Left Hand Ditch actually had 12 diversions off of Left Hand Creek (2/20 at 102). Mussetter said Andrews had assumed all of the diverted flow had gone into the one diversion ditch, and the error was on the order of 22 vs. 90 cfs (6/20 at 110-112). Altenhofen had developed a revised flow duration curve based on the lower values actually entering the ditch. This changed the effective discharge below the diversion site from 100 to 125 cfs (6/25 at 21-24).

In summary, Andrews said his effective discharge studies verified the hypothesis that the bankfull stream channel "is formed and is constructed over a period of years by those flows that transport most of the sediment," and that these flows are "a range of discharges from somewhat less than bankfull to somewhat more than bankfull that . . . transport this sediment and construct the channel." This contrasted with the objector's claims that the channels were "relic" channels formed by very large floods which occurred centuries or milleniums ago and had been basically unaltered since then (2/14 at 133-135). Andrews said coarse bed materials or densely vegetated banks could affect a channel's shape but not the relationship between effective and bankfull discharge (12/10 at 136-138).

The Judge's Arguments

The judge said Andrew's testimony was different from what he remembered Leopold as saying. He thought Leopold had "placed general reliance on the so-called channel-forming flows, which did not necessarily occur even once a year." Andrews agreed that the flows might not occur every year, but that in his mind, "channel-forming flows" and the "range of sediment-transporting flows" which he had discussed were synonymous (12/10 at 134-135).

The judge then asked how the peak of the effective discharge curve related to other flows. Andrews answered that the bankfull channel was the product of the full range of flows. The judge again said he had gotten the impression from Leopold that a "flushing flow" of bankfull discharge for a few days was all that was really necessary, and the rise/recession flows didn't make that much difference. Andrews explained that the area under the effective discharge curve represented the total sediment transported by the stream, and that most of it was transported by flows slightly below bankfull to above bankfull. To preserve the size of a channel, it was important to transport all the sediment supplied to it. A few days of bankfull flow wouldn't accomplish this (12/10 at 139-142).

The judge read this statement from Chapter 30:

"This procedure is designed to maintain the capacity of the active channel only. Therefore, the use of an effective discharge... will achieve the desired capacity maintenance objective."

He again asked why rising/recession flows were needed if the effective discharge was sufficient. Andrews said that one of the justifications for rising/recession flows was to have a certain percentage of flows on either side of bankfull because the channel wasn't "formed by one single flow that occurs for one day, but a range of flows. We use the bankfull flow to be indicative of that" (2/20 at 135-137; also Harvey 4/4 at 937).

The judge said this argument meant that the only way to preserve the streams was to keep them in a state of nature, and he didn't believe the U.S. was proposing to disallow any and all diversions. He said there must be something less than the state of nature that the U.S. felt was sufficient, but didn't understand how they derived the rise/recession flows. Andrews said to maintain a pristine stream with no impairment would require taking "all the water because that river is formed by all the water that is in it." The Forest Service was accepting some impairment of channel capacity because it was not claiming flows above bankfull. Andrews said to obtain a channel which was roughly 60-80% of the "state of nature" only required about 40% of the water (not taking vegetation encroachment into account). The U.S. claims averaged 50% of the water (12/10 at 142-144).

The State's Viewpoint

The opposition supported the concept of effective discharge developed by Wolman and Miller, but argued that it related to fully adjustable streams. They disagreed with Andrews' conclusions that effective discharge and the U.S.-defined bankfull discharge were very similar in the WD1 streams, and that these flows were the channel-forming and channel-maintaining discharges. For fully adjustable streams where the entire channel boundary would adjust at bankfull flow, effective and bankfull discharges would be similar. For the WD1 streams it did not have the same meaning (Schumm 3/21 at 118-125; Mussetter 6/20 at 86; Li 6/7 at 60-61). Harvey added that "the literature would tend to support the view that there are a range of effective discharges"—not a single discharge equal to bankfull (4/5 at 130, 142-145).

The opposition criticized Andrews' methods of computing effective discharge at the quantification points. They pointed out that:

- <u>The slopes used by Andrews were different than those given for the whole stream reach by the Forest Service.</u> Andrews explained that the slopes used in the effective discharge calculations were based on the slope between two riffles at a particular cross-section rather than the slope for the whole reach. He had "inferred" a high flow water surface slope from the riffle-riffle slope based on the bed profile, the water surface profile measured at low flows, and his own experience with measuring slopes at high and low flows (2/20 at 47-48). However, he said the effective discharge computations were relatively insensitive to changes in width, slope and bed material size (2/20 at 49).
- <u>An estimated hydraulic radius for flows above bankfull was used</u>. For flows below bankfull, Andrews had used the relationship between hydraulic radius and discharge developed from measurements. However, above bankfull he had assumed that the hydraulic radius would increase about 1/3 as fast as it did below bankfull. He agreed that if a channel were confined, his method would underestimate the above-bankfull flows and therefore the amount of sediment transported by those flows. However, he said this would have a relatively minor effect on the effective discharge peak value because flows around bankfull weren't affected by the assumption (2/20 at 32-33, 35-37; 12/11 at 55-61).

  Mussetter evaluated the actual cross-sections at the U.S. fluvial sites to see whether Andrews' assumptions were realistic. With the exception of Middle Boulder Creek, the hydraulic radius-discharge relationship did not change until the topographic top of bank, which was higher than the U.S.'s bankfull level. The true values would have shifted the effective discharge to higher values. For the Little Beaver Creek site, it would have increased effective discharge from 53 to 93 cfs (6/20 at 98-109).
- <u>The method of computing sediment transport overestimated the amount of sediment which would move.</u> As discussed in a previous section, the opposition disagreed

with the U.S.'s methods for calculating boundary shear and sediment transport.

The opposition also criticized the fact that the U.S. had only looked at the peak of the effective discharge graphs rather than the amount of sediment transported by the various discharges. They questioned why the U.S. was only claiming flows up to bankfull when in fact a substantial amount of sediment was transported by flows above that level (Mussetter 6/20 at 113-116). They gave these examples:

- Little Beaver Creek: only 37% of the total sediment would be transported by flows up to and including bankfull.
- South Fork of Cache La Poudre: only 21% of the total would be transported by flows of bankfull and below; 74% was transported by flows exceeding the effective discharge yet these flows were not claimed for channel maintenance (2/20 at 43-45; 12/11 at 49-55).

For all of the fluvial sites with the exception of Goose Creek #4, flows at and below the U.S.-defined bankfull discharge carried less than 50% of the mean annual sediment load. By making corrections for the hydraulic radius to reflect actual conditions (rather than the 1/3 assumption), this figure dropped to 15-20% in most cases (Mussetter 6/20 at 113-116).

Mussetter concluded, "if the discharges less or equal to the bankfull flow are carrying a relatively small proportion of sediment load, it is hardly reasonable to say those are the discharges doing the most work in forming the channel." This did not mean the U.S. could claim larger peak flows; in fact, SLA had determined that no flow was required to move the sediment supply at the Little Beaver Creek site (Mussetter 6/20 at 116-118; Harvey 4/9 at 139).

CONCLUSIONS

The U.S.'s Viewpoint

- The Parker equation and a dimensionless critical shear stress of 0.03 were appropriate for the WD1 streams.
- The WD1 streams were hydraulically controlled because:
  - larger particles moved at higher discharges,
  - more sediment moved at higher discharges,
  - sediment transport estimates from hydraulic equations agreed well with measured data.
- Bankfull flow = effective discharge in the mountain streams.
- At most sites, the D_{50} would move at the U.S. defined bankfull flow.
- The channel maintenance flows would transport enough sediment to keep channels from filling in. Some degree of impairment of channel capacity would occur because flows over bankfull/effective discharge were not being claimed.

The Opposition's Viewpoint

- The Meyer-Peter Muller equation and a dimensionless critical shear stress of 0.047 were most appropriate for the mountain streams.
- Measured sediment concentrations were low.
- In general, bed materials would not mobilize at U.S.-defined bankfull flows.
- The WD1 streams were supply-limited because:
  - much more sediment could be transported than what hydraulic equations predicted could move,
  - the sizes transported were smaller than those in the surface or subsurface of the streambed.
- The U.S. should have accounted for differing bed material conditions, differing sediment transport conditions and differing sediment supply conditions in its calculations of channel maintenance flows, e.g.. by using Rosgen's stream classification.
- Aggradation would not occur in the WD1 streams if flows were reduced by diversions.
- The flows claimed by the U.S. were not the minimum amount required. SLA had computed much lower "transport flows," which were zero at some sites. Richardson (7/26 at 61-62) did not believe any flow was needed to maintain the channels. Leaf (8/1 at 116-118; 8/6 at 102-104) believed only the introduced sediment (not material eroded from streambanks) needed to be transported, and therefore little if any flow was needed for channel maintenance.

AUTHOR'S NOTE

There was considerable discussion throughout the case on the opposition's last point. They argued several times that if streamflows were reduced, channel erosion would also decrease and therefore sediment yields would be less than for higher flows. The judge appeared to agree with this argument. He also believed some of the sediment would be diverted along with the flows and therefore wouldn't accumulate in the channel (2/9/90 at 41-51).

Andrews said that the channel was formed and maintained by bankfull flows, but sediment could be contributed to streams from lateral areas which could fill it and cause an adjustment. Therefore the flows forming the channel were one thing; adjustment by influxes of sediment was another and could be independent of the flows. Both were related to channel maintenance (2/20 at 23-24).

If the WD1 streams were in quasi-equilibrium, channels would be eroding and depositing at approximately the same rate in order to maintain channel dimensions. If, as Leaf implied, most of the sediment was coming from erosion of the channel itself, then the streams were not really in quasi-equilibrium and were actually degrading over time. Schumm also argued that the WD1 streams were not in quasi-equilibrium because they did not have smooth longitudinal profiles. Even Andrews said the U.S. claimed flows were not designed to maintain quasi-equilibrium but to maintain the existing bankfull channel. Therefore, it would seem that the U.S.'s channel maintenance flows would "arrest" the channels in their present state, halting their natural long-term progression towards a smooth longitudinal profile and a true quasi-equilibrium condition.

Section 7. The U.S.'s Quantification Procedure

STEPS IN THE QUANTIFICATION PROCEDURE

The object of the U.S.'s instream flow claim was to mimic natural hydrographs using the minimum flows possible. Their claim began after May 1 when the natural hydrograph reached the mean annual discharge at the beginning of the snowmelt runoff period. After two days at or above mean annual flow, the claim would begin stepping up to bankfull discharge, which was maintained for a given duration. The claim then stepped down to base flow, generally at a faster rate than what occurred naturally. Base flow was then maintained for a specified duration which could be the rest of the year (Silvey 1/30 at 90-93; Maxwell 12/4 at 150-154).

These steps were followed to develop a claim for each quantification point (QP):

- development of flow duration curves from USGS gaging station data,
- calculation of bankfull discharge at QPs based on field measurements of channel characteristics and hydraulic equations,
- computation of water yield and hydrograph components for each QP using site-specific field data and parameters extrapolated from the USGS data.

Figure 18 shows a schematic of the quantification procedure as understood by the author from reading the transcripts.[5]

Estimation of Water Yield at Quantification Points

From USGS gaging station data, Silvey developed relationships between <u>average annual runoff</u> (feet) and <u>mean basin elevation</u>. Different plots were developed for the southern and northern parts of WD1, as shown in Figure 19. Some 20 USGS stations were selected for analysis, some of which were outside WD1 to the south and west. Selections were based on these criteria:

- period of record (which ranged from 4 to 56 years),
- absence of upstream diversions, and
- location in or near WD1.

Each USGS gaging station became a "base station" for a number of quantification points. The stations were assigned to quantification points based on proximity, similarity in elevation, and runoff patterns (e.g.. snowmelt vs. rainfall) (Silvey 1/30 at 56-57, 75-78; 1/31 at 43-46; 2/1 at 65-66). Using the appropriate "North" or "South" relationship, the mean elevation for a specific QP could then be used to obtain average annual runoff. Average annual runoff (in feet) was multiplied by the drainage area (in acres) to obtain water yield in acre-feet (Silvey 1/30 at 48-50).

Calculation of Bankfull, Base Flow and Mean Annual Flow Volumes

An example data sheet from the gaging station data book [Exhibit A-516] is shown in Figure 20. Flow duration curves were developed for each of the 20 USGS gaging stations. These represented the percentage of time an individual daily flow was equaled or exceeded. Curves were apparently developed by ranking all daily flows of record and assigning them a cumulative percentage of time exceeded. If plotted on arithmetic paper, the total area under the flow duration curve was equivalent to the water yield over the period of record. The proportion of that total area above a particular discharge (e.g.. bankfull) could then be computed.

This percentage could be converted to an equivalent number of days per year by multiplying by 365.25. For example, if a bankfull flow was equaled or exceeded 5% of the time, this would mean that flows reached or went above bankfull approximately 18 days out of the year on average (Silvey 1/30 at 67-73).

- <u>Base flow and bankfull flow</u> were calculated from a rating curve developed for a cross-section at or near each USGS gaging station. Bankfull and base flow levels were identified either in the field or from the plotted cross-sections. Base flow level was considered to be the portion of the channel

[5] **Author's note**: *The author found the testimony on the quantification procedure confusing and conflicting, particularly the use of flow duration curves. The court may have been equally confused. The following discussion is based on the author's best effort at interpreting the transcripts.*

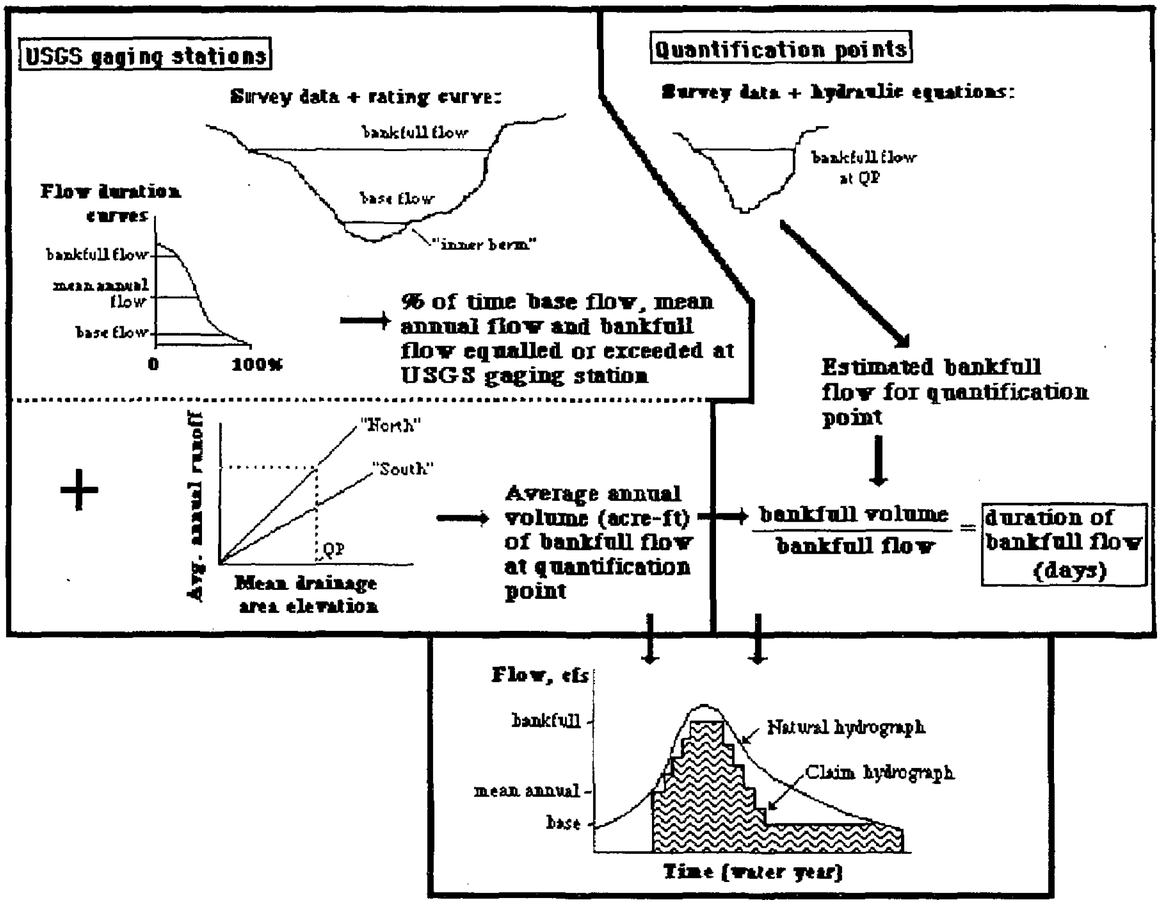


Figure 18.—Schematic of U.S. procedure for constructing instream flow claim hydrograph at quantification points (author's interpretation).

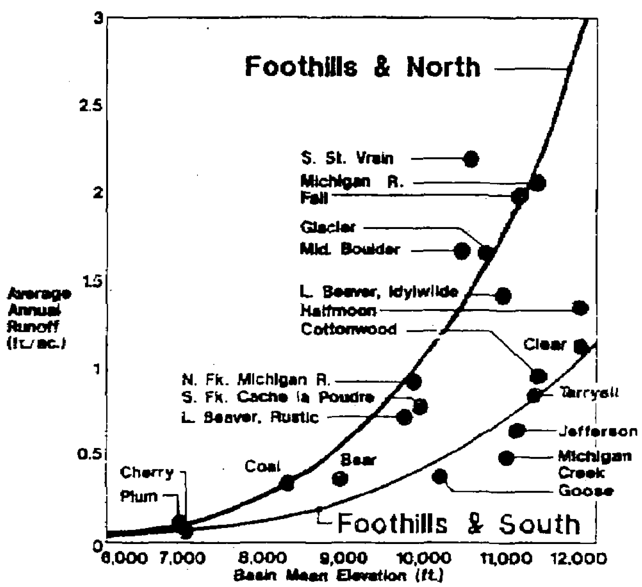


Figure 19.—"North" and "south" equations relating average annual runoff to mean basin elevation at USGS gaging stations (1989 procedure). From Exhibit [A-512].

which carried the lower flows, and was identified by an "inner berm" or other features (Silvey 1/30 at 60-66; 1/31 at 30-31).

- Rise/recession flows were those between bankfull flow and the mean annual flow. Mean annual flow in cfs was obtained from the streamflow record for the USGS gaging stations.

For the rise/recession flows, the "block" of water between bankfull and mean annual flow was converted to a percentage of annual yield. For the base flow and bankfull flows, the percentage of annual yield was computed by first calculating the number of days for which that flow was equaled or exceeded. This duration was multiplied by the flow in cfs and a conversion factor of 1.9835 to obtain a volume in acre-feet. This represented the total volume which would be produced by the stream if the index flow occurred for the given number of days. The volumes calculated for bankfull and base flow were then divided by the total annual yield for the base station to obtain percentages (Silvey 1/30 at 82-89).

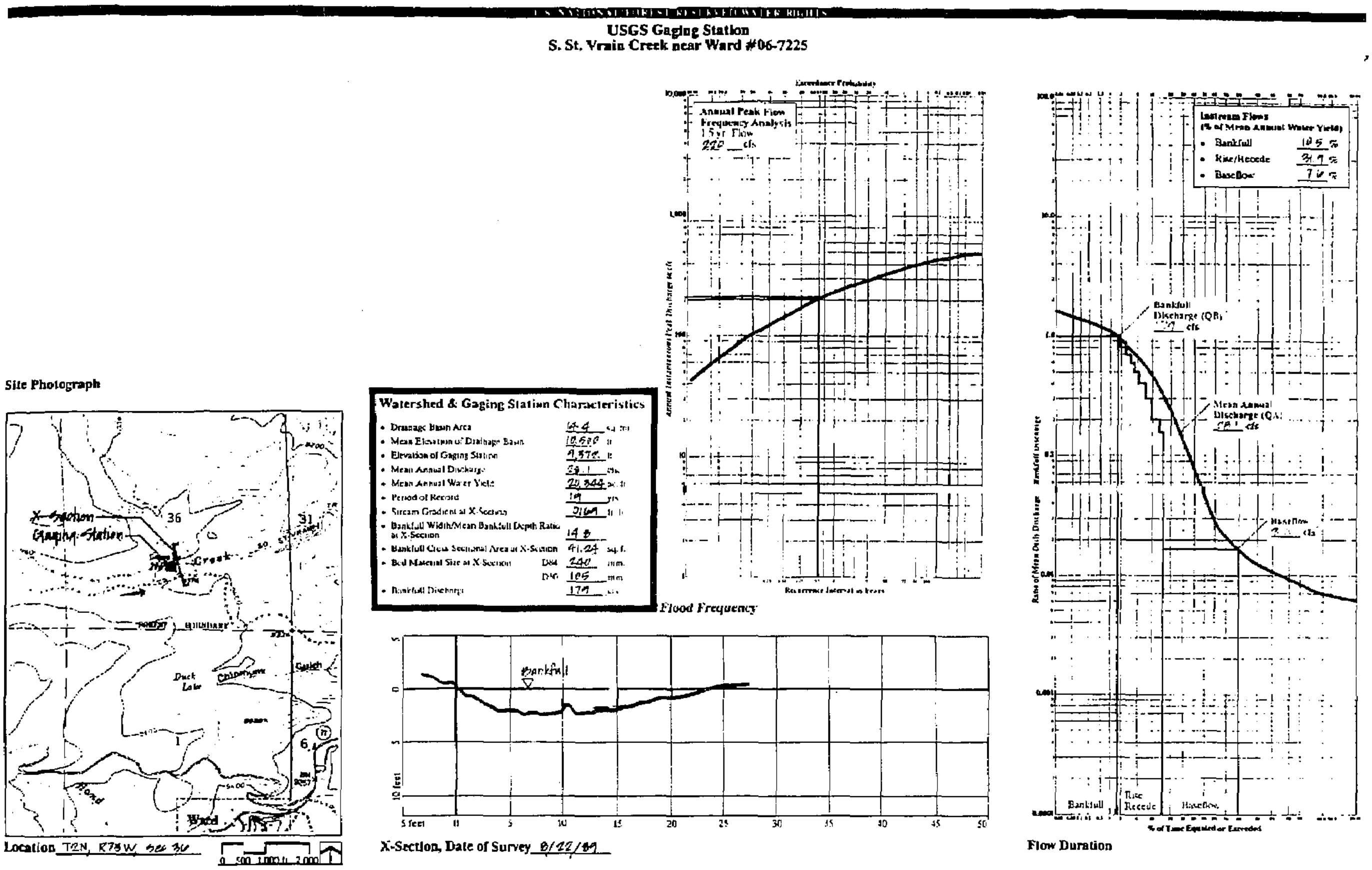


Figure 20.—Sample data sheet for a USGS gagging station on the South St. Vrain. From Exhibit [A-510].

The percentages of annual yield calculated for bankfull, base flow and rise/recession discharges at the USGS stations were then applied to the quantification points assigned to each base station (Silvey 1/30 at 75-78). The percentages were multiplied by the estimated annual water yield at each quantification point to obtain volumes or "blocks" of flow for rise/recession, bankfull and base flow components.[6]

[6] **Author's note:** *A flow duration curve actually gives the number of days that a given flow is equaled or exceeded. To multiply this duration by the flow (the "equaled part) effectively "chops off" the volume assigned to flows greater than the index flow (the "exceeded part). This was consistent with the U.S. claim, which made all flows greater than bankfull available to other water users; however, it was a rather unusual application of flow duration curves. The procedure of calculating the rise/recession volume by using an interval between bankfull and mean annual flow was more conventional.*

Computation of Bankfull Discharge at the Quantification Points

Hydraulic Equations

Because it was impractical to have research teams go to all of the quantification points and wait for bankfull flow to occur, indirect methods using field measurements and hydraulics formulas were applied. The formulas required these data: hydraulic radius, cross-sectional area, slope, and channel roughness (represented by a "friction factor" related to the size of bed materials). The formulas were developed from pipe flow formulas, which was why **hydraulic radius** was used. It was equal to cross-sectional area divided by wetted perimeter. When streams were very wide in comparison to depth, hydraulic radius approximated the average depth (Leopold 1/24 at 149-52).

There were a total of four equations used for calculating bankfull discharge: "Leopold D_{84}," "Leopold D_{50}," "Limerinos," and "Water Division 1 (WD1)." Leopold discussed the first two, given as follows:

Leopold D_{84}: $\frac{U}{U*} = 2.83 + 5.66 \log(R/D_{84})$

Leopold D_{50}: $\frac{U}{U*} = 1.00 + 5.75 \log(R/D_{50})$

where: U = mean velocity and

U* = shear velocity, both in ft/second [7]

R = hydraulic radius, ft

D_{50}, D_{84} = particle size for which 50% (84%) of stream bed particle sizes are smaller, ft

Values of R/D_{84} or R/D_{50} obtained from field measurements were entered into the equation to obtain U/U*, and then a calculated value of U* was used to solve for the mean velocity, U. This was multiplied by cross-sectional area to obtain discharge.

The R/D_{84} or R/D_{50} expressions represented the ratio of water depth to particle size, called **relative roughness**. It increased as particles increased in size and/or depth decreased. However, when depth approached the size of particles, the results were less applicable (1/25 at 15-16).

The relationship between U/U* and R/D_{84} for the WD1 data agreed well with published data, indicating that the expression was valid for use in WD1 streams. The "Leopold D_{84}" equation was selected over other available equations because it had been tested using field and lab data and was considered more conservative (1/25 at 11-18). Other equations (e.g. Hey, Bathurst, Jarrett) were considered but the Leopold equations tended to give lower estimates of bankfull discharge (Silvey 1/30 at 126-127).

Silvey explained the other two equations which were used when the Leopold equations gave unreasonable values:

- **Limerinos equation:** This was a modification of the standard Manning's equation for computing mean velocity, although the roughness coefficient, "n" was computed from an empirical relationship. The equation was:

$$U = \frac{1.486}{n} R^{0.67} S^{0.5} \text{ with "Limerinos n"} = \frac{0.0926(R)^{1/6}}{1.16 + 2 \log (R/D84)}$$

where: U = mean velocity, ft/sec

R = hydraulic radius, ft

S = slope

D_{84} = particle size (ft) for which 84% of particles are smaller

- **Water Division 1 equation:** The equation was developed from data at the USGS base stations by Dr. Ted Combs, a consultant for the Department of Justice. He developed the equation in late fall of 1989 specifically for the U.S.'s amended applications (2/1 at 51). The WD1 equation had the form:

$$Q_{bkf} = 3.998(A)^{1.02}$$

where: Q_{bkf} = bankfull discharge, cfs

A = bankfull x.s. area, ft^2

The data points and equation are shown in Figure 21. From this relationship, the bankfull cross-section measured at each QP could be used to estimate bankfull discharge (Silvey 1/30 at 119).

Selection of bankfull equation

The bankfull equations could give answers which were up to four times different (Silvey 1/30 at 123). The final selection was based on certain criteria and on the judgement of hydrologists who had taken measurements over a span of the quantification points and knew if the bankfull discharge estimates were realistic. These selections were made by forest hydrologists: Mr. Bo Stewart for the Arapahoe/Roosevelt N.F. and Ms. Lee Chavez for the Pike/San Isabel N.F using these criteria:

- Leopold equation criteria:

  When the diameter of particles (D_{50} or D_{84}) approached the mean depth (which was approximately hydraulic radius for wide streams), the equations were not considered applicable. The following criteria were programmed into the computer spreadsheet which calculated results for all 4 equations (Silvey 1/30 at 123-124; Stuart 2/6 at 130-133):

  - Leopold D_{84} equation: applied when the R/D_{84} value was greater than 1.1.
  - Leopold D_{50} equation: applied when R/D_{84} was less than 1.1 and R/D_{50} was greater than 1.1.
- If the calculated velocity was greater than about 5.5 ft/sec, the result was not used (Silvey 1/30 at 121). This was a more flexible guideline which was tempered by knowledge of what was realistic in the field (Chavez 2/6 at 10). In Leopold's experience, bankfull velocity was typically about 4 ft/sec (1/25 at 95-97). Stuart (2/6 at 113) said that he had almost killed himself measuring velocities close to 7 ft/sec, and that a maximum

[7] ***Author's note:** Shear velocity, U*, was computed as: $\sqrt{(\gamma RS)}$ with γ = acceleration due to gravity, R = hydraulic radius and S = energy slope.*

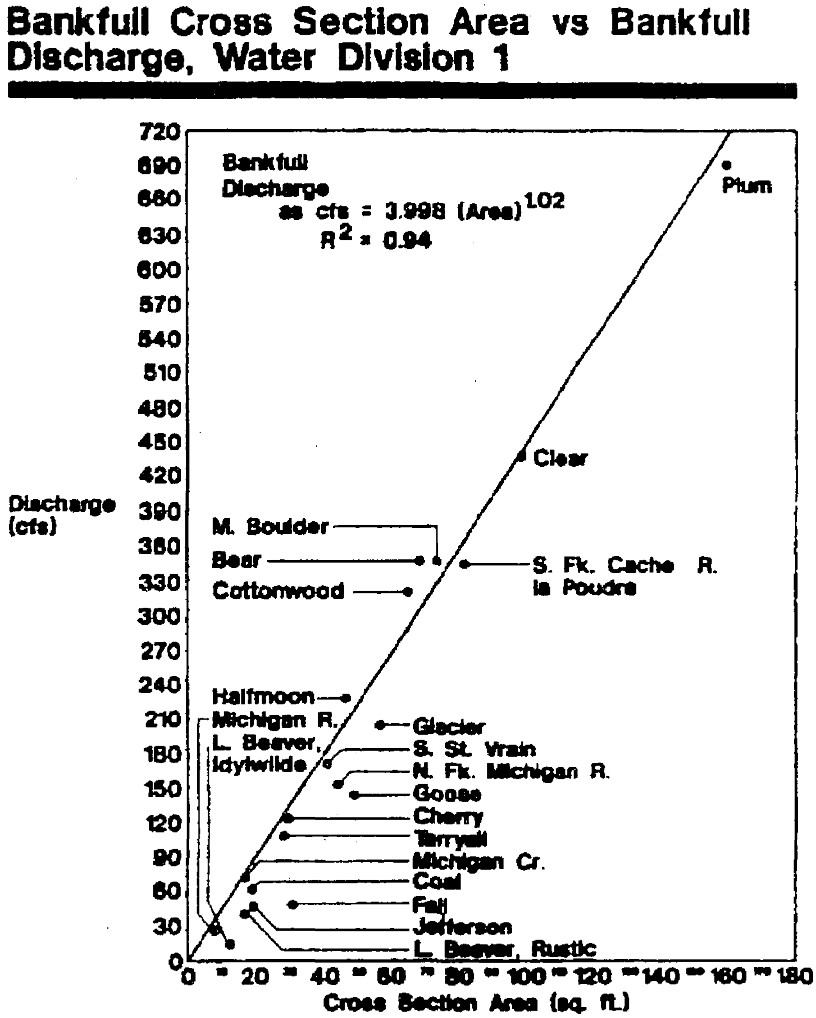


Figure 21.—The "Water Division 1 Equation" relating bankfull discharge and cross-sectional area at USGS gaging stations. From Exhibit [A-508].

velocity in the 5-6 ft/sec range was reasonable. At one site, a velocity of about 6 ft/sec was calculated, but was justified because the stream was very large (Leopold 1/25 at 143).

- The computed duration of bankfull discharge was checked to see if it was reasonable. From a study of 24 gravel-bed rivers in Colorado, Andrews found that bankfull durations ranged from less than 0.5 days to 22 days and averaged 8 days. Bankfull durations for seven of the USFS fluvial study sites averaged 6 days. For all quantification points, the durations ranged from a fraction of a day to about 22 days, with an average of 6.5 days (Andrews 2/14 at 77-78, 125-126, 132-133). Stuart considered this range to be reasonable, and rejected the results from one equation because it gave a 31 day duration for bankfull flow (2/6 at 114-116).
- Actual field measurements at or near bankfull discharge were also taken into consideration if they were available (Stuart 2/6 at 174-177).

Chavez gave a few examples to demonstrate the selection process. At one site, the D_{84} was only 0.2 mm, making the R/D_{84} factor in the Leopold D_{84} equation very large. This resulted in an overly large estimated velocity of 8.8 ft/sec. The WD1 equation was selected for this site because it gave a velocity of only 4 ft/sec. At another site, the D_{84} was close to 17 feet, which gave a very small R/D_{84} factor. This caused the Leopold and Limerinos equations to give negative velocities. The WD1 equation was again used for this site (Chavez, 2/5 at 130-140). Stuart mentioned that the Leopold and Limerinos equations could also give excessive velocities for sites with very steep slopes (2/6 at 174-177).

Weiss, an attorney for Colorado, presented this information on how many times the different equations were used (2/6 at 11-15, 23-30, 134):

	Chavez	Stuart
Leopold D_{84}	55	38
Leopold D_{50}	2	34
Limerinos	3	0
WD1	33	57

Chavez (2/5 at 131) explained that "any equation has a limitation. There is not one equation that fits everything in nature, so we used a variety – in this case four—to come up with a reasonable answer." Different equations were needed for different stream types; i.e. a wide stream with a lot of big boulders sticking out might require one equation which would not apply to a deep stream with a gravel/cobble streambed (Silvey 1/30 at 125). The U.S. experts emphasized the need for professional judgement in making the final selection (Stuart 2/6 at 110-111; Chavez 2/6 at 87).

This reliance on judgement rather than firm, objective criteria was the target for a substantial amount of criticism from the opposers. The judge said it appeared to him that it was really a judgement call on which equation to use, based on which results the forest hydrologists "liked the best." He said that "attaching scientific formulas to them gives a mistaken impression [of] the accuracy or scientific basis for what is really a professional judgement." Walch said he agreed that someone had to use professional judgement to obtain the final result, but that the equations did provide some guidance for that judgement (6/12 at 70-74).

Construction of the Claim Hydrograph at Quantification Points

The claim began when the natural hydrograph at the quantification point reached mean annual discharge and remained there for two days. The claimed hydrograph then stepped up to bankfull, stayed there for a specified duration, then stepped back down again to base flow, where it remained for a specified number of days. Previous sections explained how the "block" or volume of water for each component was obtained, and how bankfull flow was calculated. Other steps were as follows:

- Mean annual discharge was computed by taking the estimated water yield for each QP, dividing by the number of days in a year, and converting to cfs.
- Bankfull duration was calculated by dividing the bankfull volume or "block" by the estimated bankfull flow and converting to days.
- Rise/recession components were stepped up and down in 10% increments of bankfull discharge. The total "block" of rise/recession flow was computed from the percentage between mean annual flow and bankfull flow on the USGS base station flow duration curve. Durations for each "step" were also computed from the base station data. The rise/recession pattern therefore reflected the flow pattern for the gaging station. It was a modification of the 1984 procedure and essentially cut the time period for rise and recession amounts in half (Silvey 1/30 at 94-96, 101-102; 1/31 at 19; 2/1 at 76).
- Base flow discharge at the quantification points was based on the ratio of bankfull flow to base flow at the USGS base stations (Silvey 2/1 at 72). Duration was calculated by dividing the base flow "block" of water by the base flow discharge, as for bankfull. In the 1984 claims, base flow had been claimed throughout the winter (Rosgen 2/9 at 9-11). Silvey discussed a procedure of calculating a block of water under the "tail end" of the flow duration curve (fig. 22). In the 1989 claims, this amount was dropped. The "tail end" flows were assumed to occur mostly in the winter months, which were not considered as important for channel maintenance. Some claims still had base flow all winter, and some stopped when the stream ran out of water (Silvey 1/31 at 20-21; 2/1 at 74-75).

  Also for the 1989 claims, the Forest Service made a management decision to not claim flows of 0.2 cfs or less because of the difficulty of administering those flows. As a result, base flow was not claimed on about 27% of all quantification points. Base flows ranged from 0.35 to almost 6 cfs (Silvey 1/31 at 22, 32-33; 2/5 at 64).

Summary of Instream Flow Quantifications

Rosgen gave an example using 1989 streamflow data from Little Beaver Creek to show how the U.S. claims looked when imposed on an actual hydrograph. Bankfull flow was not reached in 1989 at Little Beaver Creek; therefore all of the peak flow would have been claimed. At this site, no base flow was claimed at the beginning of the snowmelt

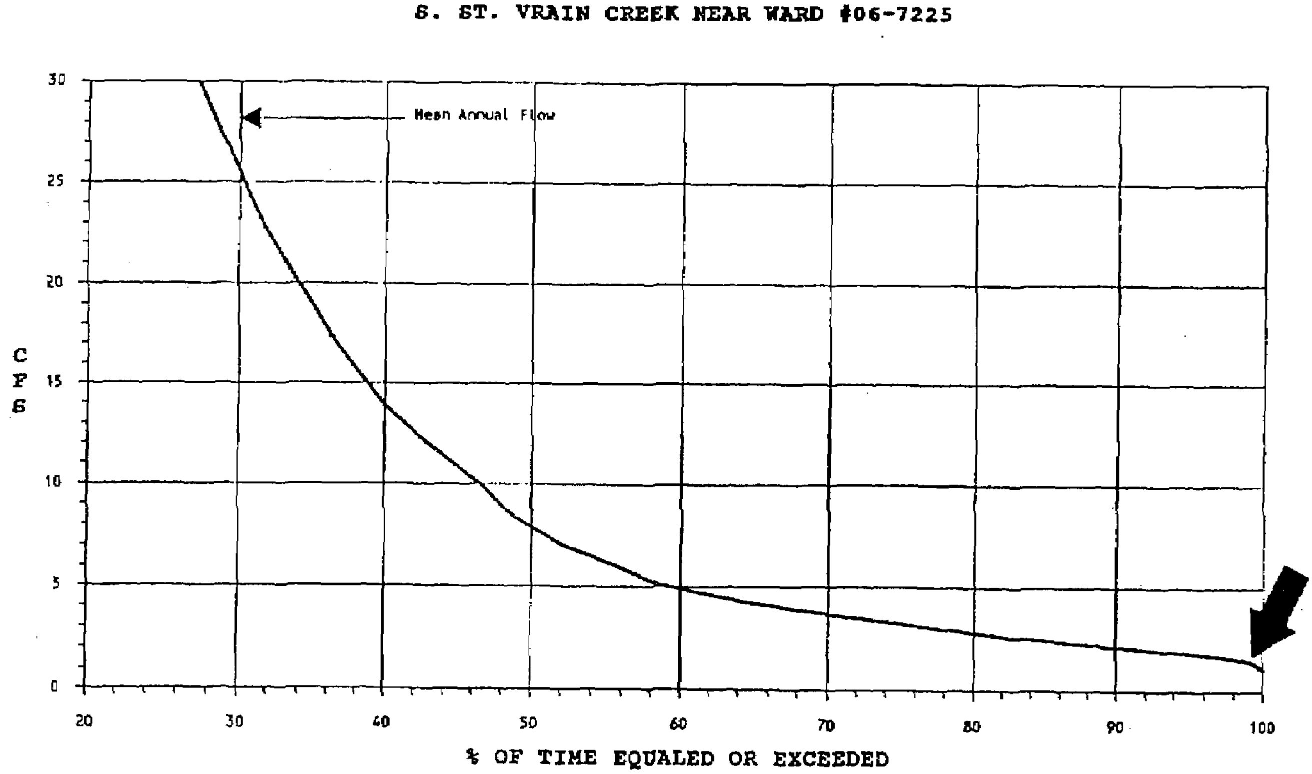


Figure 22.—Lower end of a flow duration curve showing a break in slope. Note that the graph only shows the flows exceeded at least 20% of the time. From Exhibit [A-1614].

runoff season in early May. For the same data, Rosgen demonstrated that sediment concentrations associated with base flows accounted for less than 1% of the total sediment moved in 1989. It was also composed of very fine particles. This minor significance in sediment transport was the reason for dropping winter base flow off of the 1989 claims (Rosgen 2/9 at 9-11).

For the 244 quantification points in WD1, the total volume of instream flow claimed amounted to 50% of mean annual yield or less, with the exception of 4-5 sites on the Pike National Forest (Silvey 1/30 at 111). The average percentages for individual components were:

- Bankfull: 10%
- Rise/recession: 28%
- Base flow: 12%

for a total of 50%. The remaining 50% was available for other water users (Silvey 1/30 at 116). Figure 23 shows the 1989 claim superimposed on an actual hydrograph for a year when bankfull discharge was exceeded.

The U.S. experts maintained that the claimed flows would maintain the capacity of stream channels for transmitting water and sediment, and that they were the minimum amount necessary (Silvey 1/31 at 49, 100-101; Chavez 2/5 at 140). The purpose of rise, recession and bankfull flows was to move bedload, which was important for channel maintenance. A gradual recession from bankfull to base flow was needed to prevent streambanks from collapsing under pore water pressure; i.e. the water in the stream would support the water column within the bank while the exposed portion drained. Base flow was needed to prevent vegetation encroachment and to provide some sediment transport at low flows (Silvey 1/30 at 99-100; 1/31 at 30-31).

It was the judge's opinion that neither Leopold nor Potter had emphasized the rise/recession flows which constituted the major part of the U.S. claims, and therefore the testimony of other witnesses was inconsistent with theirs. He questioned why rise/recession components were needed if bankfull did the most work in forming the active channel (1/30 at 93-94; 1/31 at 94). He also questioned why mean annual flow was used as an index value since none of the other witnesses had mentioned it. Further, he said if bankfull flows were only needed every 1.5 years, "what would be the point of depriving the water users of these flows in a year which was dry in general when in reality they wouldn't seem to be doing much for the stream bank?" (2/5 at 35-36). During Andrews' testimony,

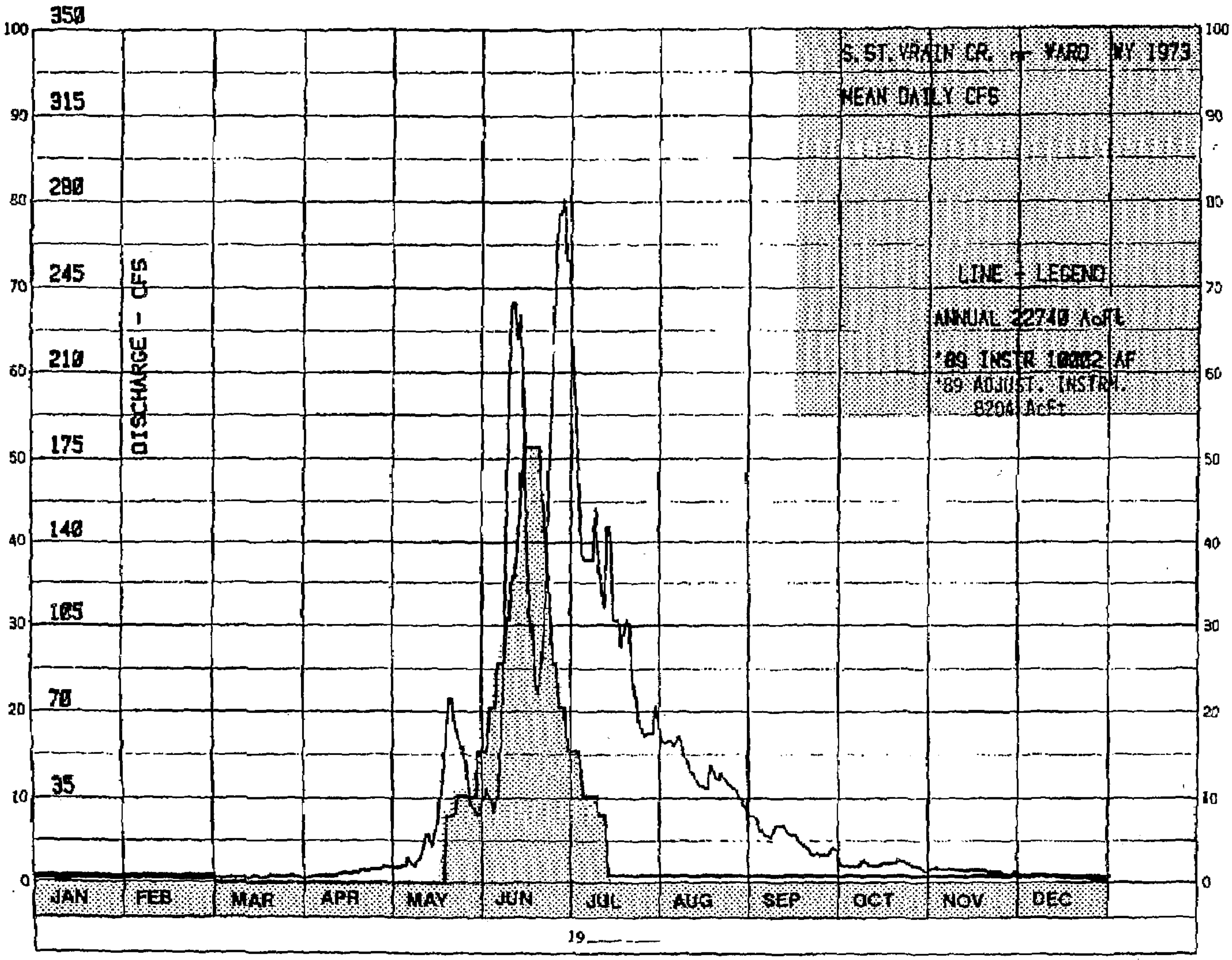


Figure 23.—Streamflow hydrograph for the South St. Vrain gaging station with the 1989 claim superimposed. From Exhibit [A-1619].

the judge said it seemed that the object of the WD1 case was to decide if it was necessary to replicate historic flows in order to preserve the stream channels. He also wondered whether bankfull flows of a shorter duration would accomplish the same purpose (2/14 at 135-136; 2/15 at 5-6).

Silvey said that during consultation with Leopold, Emmett and other geomorphologists, and from research information, they had concluded that the large majority of both suspended and bed load sediment transport occurred when flow rates exceeded the mean annual flow, and therefore the rise, recession and bankfull flows were all needed. He and Andrews also pointed out that the channel was a product of all the flows which had occurred in it, and high and low discharges were needed to move sediment and maintain the stream systems. There was a central tendency for certain flows of a certain duration to transport most of the sediment. The U.S. claims were designed to replicate the natural condition by keeping the range of flows which were most important in forming the bankfull channel, leaving the rest available for diversion (Silvey 1/30 at 93, 104; 2/5 at 36-37).

THE OPPOSITION'S CRITICISMS OF THE U.S.'S QUANTIFICATION METHODOLOGY

Estimation of Mean Annual Runoff

To compute mean annual runoff at the quantification points, the Forest Service had developed two equations based on data from the USGS base stations: "Foothills North" (basically the Arapahoe-Roosevelt National Forest) and "Foothills South" (basically the Pike N.F.). Altenhofen criticized the fact that this was an averaging procedure and because some points fell below the regression lines, a higher mean annual runoff would be predicted than what actually occurred at those sites. He seemed to imply that the U.S. should have fit a line through or below the minimum values. As an example, Altenhofen showed that the "South equation" gave 47% more runoff than what actually occurred at the Michigan Creek base station, which was one of the data points used to derive the equation (8/8 at 34-39).

Flow Duration Curves

Altenhofen referred to Chapter 30, which said the shape of the flow duration curve was largely determined by the hydrologic and geologic characteristics of the watershed it represented. It could be used to describe the behavior of other ungaged watersheds with similar characteristics after normalizing it using an index discharge, i.e. bankfull. Altenhofen said that this principle was used by water resource engineers all the time. However, the Forest Service had deviated from the standard procedure because they hadn't extrapolated durations. In theory, the durations of the normalized flows would be the same in hydrologically similar basins. Instead of extrapolating durations to the quantification points, the Forest Service had computed them from the field-estimated values of bankfull discharge (8/8 at 58-60).

Mussetter argued that the runoff estimates could have had as much or more error than the estimates of bankfull discharge. Both were used to obtain the bankfull duration. He said, "using those values to compute a duration to validate a bankfull discharge estimate is, in my mind, circular reasoning" (6/20 at 127-132).

Extrapolation from USGS Base Stations to the Quantification Points

Altenhofen argued that in order to extrapolate from base stations to quantification points, the sites had to be hydrologically similar. He also argued that there should have been hydrologic consistency between the estimation of bankfull discharge, the calculation of mean annual runoff, and the use of a flow duration curve from a base station. It was his belief that the U.S.'s methods were not consistent and the USGS base stations were not hydrologically similar to the quantification points assigned to them (8/8 at 66-70). He gave the following arguments:

- In hydrologically similar basins, <u>the shapes of the flow duration curves should be similar.</u> Altenhofen compared a flow duration curve of channel maintenance flows at a quantification point with the flow duration curve for its base station to demonstrate that the shapes were different (8/8 at 66-70).
- The <u>ratio of Qa/Qb should fall within reasonable bounds for snowmelt-dominated streams,</u> where:
  - Qa = mean annual flow, and
  - Qb = bankfull flow.

  The ratio actually described the shape of the flow duration curve. The Forest Service did not consider it. Altenhofen said Qa and Qb should have a consistent relationship, and the ratio should fall within a very tight range. He demonstrated that the ratio was lower for rainfall-dominated streams than for snowmelt-dominated streams, because the rainfall-dominated streams had more flashy hydrographs with bankfull peaks much greater than mean annual flow. Dunne and Leopold's book gave values for Pennsylvania streams where peak flows were caused by heavy rains, usually in summer, and the Qa/Qb was 0.025 for small basins and 0.1 for large basins. For mountainous, snowmelt-dominated streams in Wyoming, Qa/Qb was 0.1-0.2, with an average of 0.14 for basins of all sizes. Altenhofen said the latter values were probably more consistent because snowmelt would cover the basin more uniformly than summer precipitation (8/8 at 73-77).

  Qa/Qb values for the 20 USGS base gages varied from 0.0411 to 0.1972. From this data and the Leopold data from Wyoming (28 points in all), Altenhofen found a tight distribution in the 0.04-0.21 range, with an average of 0.14. He concluded that a Qa/Qb value outside of this range would be suspect (8/8 at 78-83). For the quantification points, he found:
  - About 40% of Qa/Qb ratios for the Arapahoe-Roosevelt sites were either over 0.22 or under 0.04. Altenhofen said either or both Qa and Qb were wrong for those points.
  - The highest ratio, 0.8, was calculated for the South St. Vrain site. There, an upstream diversion took about 85% of the water and the Forest Service planned to re-evaluate their claim (8/8 at 85-91, 147-151).

- Qa/Qb ratios at the quantification points and at their corresponding base stations should be similar. As an example, the base station on the Middle Fork near Boulder had a ratio of 0.1573 but quantification points on the same stream averaged 0.33 (8/8 at 91-96). The three lowest elevation gages had mean drainage basin elevations less than 7000 feet. Their Qa/Qb ratios ranged from 0.04 to 0.073, which was consistent with Leopold's data for rainfall-dominated streams. The U.S. had extrapolated from these to higher elevation snowmelt-dominated streams; e.g.. Plum Creek with a mean elevation of 6900 feet was a base station for 20 quantification points with basin elevations ranging from 7400 to 8800 feet. Altenhofen did not think this was appropriate because the runoff hydrographs would be different. He also pointed out that Chapter 30 methods were not applicable to rainfall-dominated streams (8/8 at 53-58, 97-104).
- Bankfull durations should be the same at the quantification points as at their base stations. Bankfull duration could be checked by using the Qa/Qb ratio as follows:

(Qa/Qb) x 365 x (bankfull volume/total water yield)

If Qa/Qb were too high, the number of bankfull days would also be too high. In many cases bankfull duration at quantification points was several times higher than at their associated base stations. Altenhofen analyzed how many quantification points (QPs) had durations within plus or minus one day of the bankfull duration at the base station. For all of the QPs, only 22% passed this test of similarity (8/8 at 91-96). Altenhofen summarized his data separately for the north and south National Forests:

- *Arapahoe Roosevelt:*
  - The number of bankfull days at the QPs varied from 1 to 31, with an average of about 7 days, compared to 2-10 days with a 4.5 day average at the USGS base stations.
  - For the 72 points where the number of bankfull days exceeded the number at the base station, the average number of days was 2.47 times higher.
  - 73 QPs had claims for the entire year.
- *Pike:*
  - The number of bankfull days at the QPs ranged from 1 to 22 with an average of 5.8 days, compared to 1-9 days with an average of 4.6 days at the base stations.
  - For the 53 points where the number of bankfull days exceeded the number at the base station, the average number of bankfull days was 2.43 times higher.
  - 34 QPs had claims for the entire year.

- Other factors besides mean basin elevation should have been taken into account in the extrapolations such as aspect, vegetation, geology, etc. (Altenhofen 8/8 at 105-106; Mussetter 6/20 at 127-132). Aspect, for example, had a strong control on snowmelt and evapotranspiration processes. Altenhofen said that even if all other things were equal, he considered plus or minus 1000 feet in elevation to be an "extreme" for extrapolation. He had worked with water balance models which also considered aspect and vegetation, and which used elevation intervals of 200-600 feet (Altenhofen 8/8 at 105-111, 128-129).
- The extrapolations were made over too large a range of conditions. Altenhofen said hydrographs from larger areas were more modulated; those from smaller areas were more flashy. He gave an example where the U.S. had extrapolated from a base station with a drainage area of 302 square miles to basins of 2-16 square miles. On about 66 occasions, fourth-order streams had been extrapolated to first order streams with 2-3 square mile basins. Altenhofen agreed with Mussetter who had said 70% of the quantification points were smaller than 10 square miles (8/8 at 105-106, 116-126).
- Flow regulation should be the same for base stations and quantification points. Chapter 30 said the base stations should have less than 10% of the total annual flow volume diverted or regulated. The Forest Service did follow this criteria; however, Chapter 30 also said if an ungaged watershed had significant stream regulation (10% or more of either withdrawals or augmentation), then the base gage should also have similar regulation. Altenhofen said this was violated on the South St. Vrain where gaging station data were extrapolated downstream to points below a major diversion which removed 85% of the flow (8/8 at 130-132).
- The number of years of data at the base station should be representative. Chapter 30 called for at least 10 years of data. For three of the base stations, there were only 4 years

of record at the time the U.S. developed its quantification procedures. By the time of the WD1 trial, there were 9 years. Altenhofen said 4 years of record was insufficient (8/8 at 132-134).

Estimation of Bankfull Discharge

Criteria for Selecting Bankfull Discharge Estimate

The opposition pointed out a number of inconsistencies between the criteria the U.S. witnesses said they had used to select a bankfull estimate and their actual procedures. They demonstrated that the U.S. experts had used the "default" equation, the WD1 equation, more often than they should have and it often gave larger estimates of bankfull discharge. Some examples follow; Chavez (2/6 at 11-15, 23-30) gave others:

- At the Little Beaver Creek fluvial site, the bankfull discharge was estimated at 55 cfs. A quantification point was located upstream, at which bankfull discharge was estimated as 44 cfs (Rosgen 2/8 at 91-98). The opposition criticized this difference, saying 11 cfs would make a great deal of difference to an irrigator (Trout 2/12 at 143-146).
- On Trap Creek, the quantification point bankfull estimate was 36 cfs, but a fluvial site upstream had an estimated value of 150 cfs, with no diversions in between. Altenhofen questioned what this meant in terms of quantifying "upstream in a like manner" (8/7 at 150-153).
- The opposition pointed out several examples where a bankfull discharge had been computed but the calculated duration was zero days because the volume was insufficient. Chavez explained that claims were not made for less than one day of bankfull flow because they would be difficult to administer. Rise/recession flows were also rounded to the nearest day, which could result in rapid changes from one to the next; e.g. Trout gave an example of one claim which dropped from 76.3 cfs to 22.9 cfs (2/6 at 18-22; 2/1 at 83).
- At one of the Goose Creek sites, criteria were met for the D_{84} equation which gave 102.4 cfs, but the WD1 result of 220 cfs was selected. For a USGS station only 3000 feet downstream, the bankfull estimate was 143 cfs (Silvey 2/5 at 14-15; Rosgen 2/13 at 50-54). Chavez (2/6 at 27) defended the selection because a near-bankfull flow of 180 cfs had been measured in the field.

The last comparison was the subject of a discussion on how bankfull estimates would affect the total claim. Rosgen said variations in bankfull estimates wouldn't make any difference because the "block" of bankfull flow as a volume was calculated separately. A lower bankfull discharge estimate would just mean it would have a longer duration (2/13 at 59). He attempted to explain the difference in the claim if the bankfull discharge estimate was 143 vs. 220 cfs. A duration curve based on daily data from the gaging station gave 4 days of bankfull flow for 220 cfs or 8.5% of the annual runoff. At 143 cfs, it gave 9 days or 12.6% of total. However, the rise/recession flows would have a shorter duration for the 143 cfs vs. the 220 cfs bankfull, resulting in a total % of water yield for rise/recession/bankfull of 35 to 36% for both situations. Baseflow didn't change much. Rosgen therefore concluded that the overall effect of the claim in terms of total available water wouldn't change—just the distribution (2/13 at 150-153).

An opposition attorney then said, "so what you are saying is that it doesn't matter what the bankfull discharge computed is, because you can take all the water available anyway?" (Ventura 2/13 at 59). Another argued that the different flows would mean a change in the temporal distribution of the water, which could affect junior diverters wanting to divert water during the high flow period (Trout 2/14 at 5-7). Weiss had earlier asked Stuart if he had ever considered using, say a Leopold equation, but reducing the total water yield if the duration turned out to be too long. He said no, because they were relying on the duration from the USGS base station, and agreed that they were "locked into using the entire block of water" (2/6 at 141-142, 146-148). The judge said he didn't understand Rogen's reasoning, and that it seemed that he was saying the bankfull magnitude didn't make any difference in determining how much water was needed to maintain the channel (2/13 at 156-159).

Altenhofen summarized the results obtained from the four equations and found that the maximum value was about 2.9 times the minimum value on average for the Arapahoe-Roosevelt N.F. streams (8/7 at 138-144). Sansone said the Forest Service had selected the lowest of the four values about 41% of the time, and had not used the largest value 81% of the time (2/1 at 34).

In reference to future claims, Ventura asked whether it might be possible to have different procedures and equations 10 years in the future, and whether different people might be applying their "professional judgement" to make decisions. Chavez asserted that the equations used in this case were the best available, but that better ones might be available in 10 years, and they would use the best knowledge at the time (2/6 at 81-86).

The WD1 Equation

Mussetter said the WD1 equation appeared to significantly over-predict bankfull discharge, even for the streams from which it was supposedly derived. It was applied to about 90 of the 244 streams or 37% of the time. The opposition presented numerous criticisms of this equation.

At a very steep stream with "house-sized boulders," the Leopold and Limerinos equations both gave negative velocities, so the WD1 equation had been used. Kahn asked if any of the data used in developing the WD1 equation was from streams with similar conditions, to which Silvey answered no (2/5 at 16-17).

Mussetter demonstrated that in the WD1 equation, which was given as:

$$Q = 3.998A^{1.024},$$

the exponent on cross-sectional area was nearly 1.0. Q could then be divided by A to obtain:

Velocity symbol ≈ 4 feet/second

Therefore the estimated bankfull velocity for all streams on which the WD1 equation was applied was about 4 feet per second. Mussetter did not believe this was valid (6/12 at 75).

Altenhofen mentioned that the WD1 equation only considered cross-sectional area, but other factors should have been used such as roughness, slope, wetted perimeter, etc. The regression line was an average relationship with scatter about the line, and could over-estimate on a site-specific basis (8/8 at 32-34).

A key argument by the opposition was that the WD1 equation did not appear to fit the data points. The majority of points clustered near a bankfull cross-sectional area of 60 square feet or less, and the largest area was 105 square feet at the South St. Vrain. However, almost all of these points were below the fitted line, meaning the WD1 equation would overpredict discharge for the smaller cross-sections. The largest stream on which it had been used had a cross-sectional area of 60 square feet, and the average area was about 12 (Trout 2/1 at 54-58; Altenhofen 8/8 at 22-27).

The U.S. had used a weighted least squares method to fit the equation to the data in order to reduce the error. The larger values had been weighted more than the smaller ones; therefore it didn't fit the data well in the range which the U.S. was using for prediction. It meant the equation would give higher bankfull discharges with lower durations than what actually occurred in the streams (Mussetter 6/12 at 34-41, 78, 81-82; Silvey 2/5 at 77).

Both Altenhofen and Mussetter re-plotted the data and fit a non-weighted regression equation to it. For larger cross-sectional areas, the equations converged; however the non-weighted equation gave much lower bankfull estimates for the smaller cross-sections. Overall, the equations showed a 2.1 to 2.7-fold difference. There were no data points at the lower end of the relationship, so for very small streams, Altenhofen said the WD1 estimate was a "pure guess." The opposers concluded that the WD1 equation was not appropriate and did not even fit the data from which it was derived (Mussetter 6/12 at 78, 81-82; Altenhofen 8/8 at 22-33, 41-45).

The State's Bankfull Discharge Equation

Mussetter calculated bankfull discharge for the SLA study sites using a variation of the Chezy equation which he developed (6/12 at 54). He explained that Manning's equation wasn't appropriate for the mountain streams because of the large bed materials. In his opinion, the relative effect of these materials would change as the water got deeper. However, for the streams studied by SLA, many had rocks which protruded through the water even at bankfull flow. He said many researchers described this effect using **relative roughness**, which he computed as:

relative roughness = average water depth/D_{84}

Mussetter said a value of 0.5 would represent "large scale" roughness, compared to a value of 4 for "small scale" roughness. Most of the SLA sites were in the intermediate to large scale roughness range even at bankfull flow (6/12 at 31-35).

He tested existing flow resistance equations by Jarrett, Bathurst and Hey, and found that none of the equations were adequate for the coarse-bedded mountain streams. For the most part, they under-predicted resistance, meaning they would overpredict velocity, discharge and shear stress. He also tested the Leopold D_{84} equation and came to the same conclusion (6/12 at 35-41).

Mussetter decided to develop new equations for computing bankfull flow which more accurately described flow resistance. Factors he included in his equation were:

- the ratio of the mean depth to particle size (D/D_{84}),

- a gradation coefficient to describe the range of sizes of the coarser materials (D_{84}/D_{50}),
- channel gradient.

Field measurements of these factors and mean velocity at the SLA study sites were used to develop "essentially regression equations." Separate equations were developed for different ranges of gradient and roughness. These equations were then tested using data from the publications on the Hey, Jarrett and Bathurst equations, and on the original data. In general, he found that his equations fit the National Forest data better than the others (6/12 at 41-47).

In Mussetter's opinion, his hydraulic equation which involved several parameters was much superior to the WD1 equation which only used cross-sectional area. He also compared SLA's bankfull discharge estimates to those calculated by the U.S. for the same sites. Eighteen sites were available for comparison in WD1. The SLA estimates of bankfull discharge were typically higher than the U.S.'s, although some were lower. Mussetter attributed the differences to the different definitions of bankfull stage, different methods of calculating bankfull discharge and variations in where the SLA and U.S. cross-sections were located (6/12 at 54-58, 65-69, 83).

Mussetter concluded that his hydraulic analysis indicated that the channel capacity of many of the streams was greater than the peak flows claimed by the U.S. Therefore, even if there were a reduction of channel capacity, it was not likely to cause significant flooding impacts (6/19 at 39).

Structure of the Claim

The objectors commonly made the interpretation (Walch called it a "misinterpretation") that the U.S. claims would take 100% of the flow in dry years (2/5 at 32). Fischer used an average hydrograph for the South St. Vrain River to demonstrate that the U.S. claims were 100% of the flows for about two weeks in June in an average year, and that the majority of the claimed flows were in May and July, with more available for other users in fall and late summer (1/31 at 115-119).

There was some confusion over the interpretation of the average annual hydrograph. Kahn pointed out that the average annual hydrograph for the South St. Vrain River did not exceed bankfull discharge, and asked if that meant that bankfull was not reached on the average (1/31 at 34-5). Silvey showed a plot of all years of record for the South St. Vrain River to illustrate the fact that any given year could have flows at or exceeding bankfull. However, when the yearly hydrographs were averaged, the average hydrograph appeared to peak below bankfull. Silvey said it actually represented "sufficient bankfull occurrences to meet the instream flow maintenance needs" (2/5 at 41-42).

Silvey developed a new exhibit showing hydrographs for the South St. Vrain near Ward and the U.S. claims, for average, wet, and dry years (1956, 1975 and 1966, respectively). The percentages of flow going to the U.S. instream flow claims in each year were (2/5 at 39-41):

- average, 51%,
- wet, 36,; and
- dry, 52%.

Silvey said even though the U.S. could claim up to bankfull flow, during dry years they would take only the flows available during peak runoff, with no attempt to make up the "lost" flows later on (2/5 at 33-35). He also pointed out that the claimed flows would still be available for use *outside* the National Forest boundary because they were non-consumptive amounts; however, he agreed that diversions or impoundments within the National Forest could be curtailed (1/31 at 115-119).

Trout argued that during the "dry year," the Forest Service would be claiming 100% of the flow from roughly May 10 to June 18th. He also asked if there was a need for channel maintenance flows at all in a year when the flow was lower than average. Silvey said yes, but that the amount may be different. Silvey went on to say there could be some modification of the method to adjust for wet and dry years—that it was technically possible and would be consistent in terms of maintaining the stream system (2/1 at 88-91). Walch later addressed this point by saying that under Colorado law, it was "first in time, first in right" and water rights were not adjusted for low flows (2/5 at 44).

The U.S. Quantification Procedure Didn't Agree with Chapter 30 Procedures

One criticism of the U.S.'s procedure was that it deviated from methods described in Chapter 30. The "Water Division 1" equation was also developed specifically for the WD1 case. Chapter 30 described a method of breaking down the flow duration curve to determine flow patterns, and the WD1 claims were not based on that procedure. Mussetter also believed that the justification for the rise/recession flows was ill-founded and that the base flow claims had been filed for an extensive portion of the year without any justification (6/20 at

119-122, 132). Silvey had previously agreed that base flow was not calculated using Chapter 30 procedures (2/1 at 33-34).

INJURY TO OTHER WATER USERS

The U.S.'s Viewpoint

The U.S. had a continuing objection that the issue of injury was not relevant. They maintained that injury to other water rights was irrelevant to the issue of whether or not the U.S. was entitled to water. The judge said his understanding of the opponent's arguments was that the granting of the U.S. applications would "seriously jeopardize the flexibility that has characterized the water administration system of the state"—and that water use was "one of the things that was to be encouraged by the creation of the national forests" (9/17 at 33-34).

Rosgen said existing water rights were not being affected in the sense the U.S. wasn't proposing to maintain pristine channel dimensions; i.e. the stream conditions reflected the effects of existing diversions. In regard to impacts on wells and springs, Rosgen said the bankfull condition was mainly dependent on snowmelt runoff, and groundwater would not make much of a contribution; therefore there might not be a need to administer wells or springs (2/13 at 162-164).

The Forest Service had been able to settle with quite a few of the opposers, and in many instances there was sufficient water to meet both the U.S. rights and the absolute water rights, sometimes with modification of reservoir operations. There had also been a few settlements with holders of conditional water rights. Walch emphasized that settlement was on a case-by-case basis and involved an analysis of water availability and the amount claimed by the U.S. at those points (Walch 2/13 at 164-167; Chavez 2/5 at 143; 2/6 at 33-35).

Stuart had looked at some 20 streams on the Arapahoe-Roosevelt National Forest to compare water rights of other users to the U.S. claims. This included water rights senior to the National Forest reservation date which were downstream of the forest boundary. He found that "by and large . . . there was ample water to meet the needs of other water users as well as meet our needs for instream flow claims" (2/6 at 102). He gave two reasons for this:-

- The rights of other water users were below quantification points
- The U.S. was only claiming about 50% of the streamflow

Stuart had plotted hydrographs for the streams and looked at claims on a monthly basis, and indicated that "there seemed to be enough," but that "there were some difficulties" which he didn't explain (2/6 at 102-103).

Weiss, an opposition attorney, asked Stuart whether some diversions might be restricted during part of the year if the U.S. claims were granted. Stuart answered that it was conceivable; he also agreed that the 50% figure was for an average year. His analysis hadn't taken into account the history of calls to determine whether a downstream senior user could call out an upstream junior user during periods when the U.S. wasn't claiming most of the flow (2/6 at 149-154).

The judge pointed out that the Forest Service could say they needed a certain amount of water, but if they weren't "Number 1 call" on the stream, they might not get it. Walch said, "if somebody in Fort Lupton is pulling it through, it is going to go through regardless of whether we have an instream flow claim," to which Ventura added, "that is the point" (2/13 at 74-75). One of the opposition's arguments was that since downstream seniors would pull water through the National Forests anyway, the U.S. claims were not needed.

The Opposition's Viewpoint

Assessment of Potential Injury

The U.S.'s 1989 application for water rights contained these phrases (8/7 at 97-98):

> *"In the event that natural flows are less than the quantities claimed . . . above, the United States claims the flows actually occurring during those periods subject to valid rights having priorities senior to the reservation date."*

> *"For the entire reach of each stream above the respective point of quantification, those instream flow components ... quantified proportionately in a like manner."*

Altenhofen and Mussetter (6/20 at 133-136) said that they had not heard during the trial what the latter specifically meant.

A concern of the opposers was the *potential* impact of a new, large senior water right on other water users. Altenhofen analyzed the extent of junior water rights which were upstream of the quantification points and could potentially be called out by the Forest Service claim; he had also analyzed senior rights. In his analysis, he looked at the types of structures, the magnitude of diversions, and which quantification points would affect which water rights. This was a potential impact. He said the actual effect could not be evaluated without a site-specific analysis in reference to a specific runoff hydrograph. For example, in a wet year there might be sufficient water for all users, whereas in a dry year the U.S. could put a call on the stream which would prevent junior water users from diverting (8/7 at 94-97).

Altenhofen identified the location and priority date for water rights with diversions within the National Forests, both junior and senior to the Forest Service's priority date. Some rights had earlier appropriation dates, but had not been adjudicated until later—Altenhofen did not know if these would be treated differently than junior rights. Right No. 1 in Colorado had a date of December 31, 1849 (8/7 at 101-107).

The water rights were identified by appropriation date by the type of diversion: wells, springs, reservoirs or ditches. Wells were classified by whether they were domestic and less than 15 gpm (typically exempt) or whether they were larger and typically covered by augmentation plans. He did not include any wells which had not been adjudicated (8/7 at 108-111). The upstream junior water rights totaled 1004 in number; if wells less than 15 gpm were included, the total was 1514 (8/7 at 114-120).

In total, approximately 60% of the quantification points (QPs) had no private land upstream. About 21% had minimal private land upstream. The remainder, 19%, had more than 25% private land along the streams above the QPs. For the QPs with no junior water rights above them, the U.S. claims would pertain to future, not existing development (8/7 at 121-126).

There were three key areas with heavy concentrations of upstream junior water rights which would potentially be affected by U.S. claims: Lone Pine Creek (which affected the Red Feather area); the Allenspark area, and the Woodland Park area. The Forest Service had dropped some quantification points from its 1984 claims when it re-filed in 1989. Among them were Tarryall Creek and Boulder Creek, which had extensive private lands and junior water rights upstream of the QPs. Altenhofen was attempting to demonstrate that the U.S. had considered injury to other water users when developing its claims (8/7 at 120-124).

So far, there had been about 36 stipulations between the U.S. and other water users. These represented about 191 rights, 19% of the 1004 total number or 15% of the 1514 which included wells less than 15 gpm. The water users who had typically stipulated had larger rights (e.g. subdivisions) than the 81% which hadn't (Altenhofen 8/7 at 132-134).

The typical upstream junior water right was very small, drawing from small wells, springs, ditches and pipelines, and averaging about 2.3 cfs per right. Only 10 rights exceeded 10 cfs; one was 60 cfs, but it was a diversion which hadn't been used since 1957. The 214 adjudicated decrees for filling reservoirs averaged approximately 150 acre-feet each. The rights for 258 springs only totaled 23 cfs; and for 735 wells (absolute and conditional) the total was only 29 cfs (8/7/90 at 126-127, 130). Altenhofen showed a photograph of a 2.7 cfs, typical high mountain diversion which was basically a pile of rocks and old logs. He did not believe the Forest Service would be concerned about these types of diversions in terms of channel impacts (8/7 at 128-129).

Altenhofen argued that the small amounts diverted by water users could easily fall within the variability of picking bankfull stage or estimating bankfull discharge (8/7 at 138-145, 153-154). For example, at Lone Pine Creek, the difference between the WD1 and D_{84} equations was 48 cfs for 10 days or 960 acre-feet total, which would make "a world of difference" in terms of which water rights were called out when the Forest Service wasn't getting their claim. For this quantification point, the upstream junior rights for springs and wells only totaled 3 cfs, and junior absolute reservoirs had rights of 815 acre-feet. These were within the variability of the Forest Service's calculations (8/7 at 146-150).

From his "injury" analysis, Altenhofen concluded that there were extensive upstream junior water rights which could be affected by the U.S. claims, that the diversions involved small amounts of water, and that their rights could be called out simply due to the fact that the Forest Service's claims contained a lot of variability. If they were called out because the Forest Service was working on the upper end of that variability, then he believed the claims were not fair or reasonable, and constituted unnecessary injury (8/7 at 154-155).

Altenhofen said that without exception, the junior upstream water users obtained their water from the National Forest and benefited from it being there because it made the flow more even and steady and preserved its quality and quantity. It was these water users whose rights could be called out by the U.S.'s instream flow application (8/7 at 124-125).

Altenhofen also discussed the effect of downstream senior calls. There were times of the year when calls would come in from large direct flow irrigation diversions. On the Poudre, the call typically came during the second to third week in June, during the recession of the spring snowmelt hydrograph. It was random, and could come on as early as April or as late as the middle of July—and might never come on in a wet year. Upstream users wouldn't necessarily stop diverting during this time because many of them had worked out exchanges or augmentation plans to supply downstream users with water. Altenhofen said an upstream senior water right such as the U.S.'s would have a different effect than a downstream senior right because flows couldn't be stored upstream by junior users and released to satisfy the Forest Service's demands (8/7 at 173-175).

Quantitative Analysis of Impacts of Forest Service Claims

In Altenhofen's opinion, the 50% figure given by the Forest Service as the average annual flow available to water users had nothing to do with actual impacts on water rights. He analyzed daily flows for 19 of the USGS base gaging stations for every year of record and superimposed the U.S. claims to determine how often the claim would actually be met. He used daily data because water rights availability was administered daily by the State Engineer Office and because the U.S. claims were for daily data. Claims had not been made at the USGS stations; however some had quantification points below them (8/7 at 156-157, 159-163; 8/8 at 14).

Altenhofen explained the U.S.'s claim as follows (8/7 at 163-166):

> *Sometime after May 1 when the flow in the stream reached mean annual flow and stayed there for two days, the claim would begin. On the third day the bankfull claim would start stepping up to bankfull and then remain there for the required time. The claim then stepped back down to mean annual, and from there to a base flow.*

The application had no time limit on when it could start—just sometime after May. In one of his analyses, Altenhofen found that the claim would have started as late as June (8/8 at 5-7).

Altenhofen said his analysis of the USGS data illustrated the danger of using averages in a water rights application. The U.S. claims were based on an average of random events; e.g. in one case, a bankfull event of 6 days was averaged with 8 years of no flow to obtain a duration of 3 days of bankfull. When the bankfull claim was applied back to the site, it didn't even hit the bankfull events, but took all of the flow at other times. As a result, an upstream junior user couldn't divert or store water in most years. Out-of-priority storage in upstream reservoirs generally took place on the rising limb of the snowmelt runoff curve in May and early June (8/7 at 168-172).

He gave an example from a rainfall-dominated gage on Coal Creek, at an elevation of 7000 feet. From climatic records, he showed that the flows reaching bankfull were due to random rainfall events. At this gage, the U.S. bankfull claim was only reached twice in 23 years of record, and only once for the required number of days. At Cherry Creek gage, another rainfall-influenced gage in the plains, the bankfull claim was only met one year out of 49 years of record. This would mean the Forest Service would have a right to all the natural flows in most years, subject to upstream senior water rights (8/7 at 163-183; 8/8 at 12-14).

Even on a snowmelt-dominated stream with a mean basin elevation of 11,300 feet, Michigan River, the Forest Service's claims kicked in before bankfull actually occurred and the claims were only met one year out of the 16 years of record (8/8 at 8-10).

Altenhofen constructed graphs of the flow data for each gaging station for each water year, with the Forest Service claims superimposed. He found that:

- For the 9 Arapahoe-Roosevelt gages, the bankfull claim was met one day or more in only 19.3% of the years of record. The full bankfull claim was only met in 8.2% of the years.
- For the 10 Pike gages, these figures were 15.3% and 6.9%, respectively.

Altenhofen said this would mean the Forest Service could have had a call on the streams for the entire bankfull period for 80.7 to 84.7% of the years, on average. There was therefore a high potential for impact on water users. The rise/recession claim also exceeded the actual streamflows in some years (8/7 at 176-183; 8/8 at 5-7). Leopold had said bankfull should occur in 67% of the years—every 2 out of 3. Altenhofen argued that the Forest Service wouldn't even get what they wanted with these claims. In some years, the U.S.'s bankfull flow didn't occur at all; in other years, it occurred before or after the time of the U.S. claims (8/8 at 15-20).

The USGS base station gages on which Altenhofen had done his analysis were the basis for extrapolation to the quantification points (QPs). It was Altenhofen's opinion that these same impacts would occur at the quantification points; e.g. all the flow would be claimed in most years (8/7 at 183-184). The claims would also affect future development because claims extended upstream of the quantification points (8/8 at 14-15).

Altenhofen concluded that the U.S.'s quantification procedure was suspect: the North-South equations using average relationships with variability were suspect, the procedure of identifying bankfull stage in the field was suspect, and their judgement about which basins were hydrologically similar was suspect. Altenhofen acknowledged that regression analysis was a standard technique in hydrology, but said it was not appropriate for this case where the concern was with obtaining the absolute minimum claim. Applying an average relationship back to the actual data resulted in a higher claim in some cases. This would cause an unexpected, unnecessary injury to water rights, past and future (8/8 at 39-40, 96-97).

Altenhofen also brought out that Andrews had said the number of days duration at bankfull discharge was a function of the amount and size of sediment that had to be transported. However, the extrapolations made by the Forest Service did not consider sediment transport characteristics, sediment sources or sizes of sediment, by evaluating them at base stations as compared to the quantification points. The U.S.'s claims were based on a hydrologic extrapolation "with the assumption being that they need bankfull" (8/8 at 144-146).

The Minor Objectors

Red Feather's Case

In 1888, Mitchell Ditch was constructed to take water out of North Lone Pine Creek to fill Red Feather Lakes, which were on private land within the National Forest. They were used for irrigation, fishing, recreation and domestic use. Most of the domestic water supply was from wells. The lakes had to be at a high level by winter because they were shallow and subject to winter fish kills (Palos 9/17 at 5-8; Frydendall 9/17 at 106-108).

One of the reasons why Red Feather was resisting the U.S. claims was that the watershed above the Mitchell Ditch was small and didn't yield sufficient water to meet all demands. Red Feather's rights were called out every year by a downstream senior user. They were generally only able to divert from late May through June. To supplement this water supply, they had also purchased additional shares in water rights exchanges, e.g. on Elkhorn Creek. The U.S.'s claims covered the time when Red Feather normally diverted water. On North Lone Pine Creek, Red Feather had historically diverted the entire flow at certain times. Palos said, "it is clear in my mind that Red Feather would be seriously impacted" by the U.S. claims. He also believed that some of the domestic wells in the Red Feather area would probably go dry if the claims were granted because the lakes couldn't be filled and they kept the water table high (9/17 at 57-62).

Palos mentioned that the U.S. had stipulated with other water users on Elkhorn Creek, which effectively made the stipulators' claims senior to the U.S.'s and therefore senior to Red Feather's, whereas they had previously been junior. Palos argued that Red Feather's rights should be satisfied first. He also mentioned that one of the users with whom the U.S. had stipulated was not required to pass a base flow at the Mitchell Ditch headgate (9/17 at 62-77).

There were almost no historical records on Red Feather's diversions. Frydendall said there was only one time that he had seen more water in the stream than what the ditch could divert. He estimated its capacity as 12 cfs (9/17 at 114-115). In 1990, the Forest Service installed stilling wells with pressure transducers for recording stage above and below Mitchell Ditch. Gabbert used the records to show that some water had been diverted from May 23-29 to fill the lakes, and that all of the flow had been diverted from about July 1 to the end of record on August 15. Most of the later flows seeped into the ditch and didn't reach the lakes. Red Feather witnesses had testified that it took them about 10 days and 150 acre-feet to fill the lakes, but the 1990 measurements showed they had accomplished this in 6 days in May with about half the water (10/1 at 122-132, 155-157).

Red Feather witnesses argued that the last two years were good years in terms of snowfall, with early spring rains, meaning they could fill their lakes more quickly. However, Gabbert used SCS records to show the 1990 May and June snowpack was below average. He said they were obviously capable of filling the lakes even during dry years. The records also showed that they had come close to meeting the U.S. claims in the downstream channel just under their normal operating procedures. The creek was at or above the U.S.-estimated bankfull level for about 16 days (10/1 at 140-146). Lawrence later presented precipitation data from February-April 1990 which showed it was above normal. Gabbert didn't know how full the Red Feather lakes were before they were filled in May (10/1 at 159-172; 10/2PM at 30).

Zane brought out that the portion of North Lone Pine Creek below Mitchell Ditch headgate was "hardly recognizable" as a channel anymore. All three of Red Feather's witnesses referred to a dry section below the Mitchell Ditch which had not received water since about 1935. It contained vegetation including trees and was more like a mountain valley. The Forest Service surveyed the downstream channel in 1990. Gabbert said he had had difficulty finding new bankfull at that location; in some places he thought the feature may have been due to log jams or possibly beaver dams. Below a diversion on Elkhorn Creek, the channel was better defined. In this creek, water was allowed to flow downstream a majority of the time (Barker 9/17 at 133-134; Zane 9/17 at 96-99; Gabbert 10/2AM at 76-79; 10/2PM at 4-10).

Lawrence (1/31 at 141-146) also discussed the impacts caused by the U.S. using incorrect selection criteria to obtain a bankfull discharge estimate. For the quantification point on North Lone Pine Creek, criteria were satisfied for the Leopold D_{84} equation which gave 64.6 cfs. However, the WD1 equation was selected which gave 112.7 cfs. Bankfull claims on Elkhorn Creek were for 16.6 cfs. Again, the D_{84} criteria were satisfied and that equation only gave 7.7 cfs.

South St. Vrain

Water users in the St. Vrain and Left Hand Ditch Water Conservancy District opposed the U.S. claims. One argument was that U.S. witnesses had testified that water rights were considered in establishing the quantification points (Blaue 9/13 at 70-71). Some 325 water rights would be junior to the U.S.'s, not including 222 wells of less than 15 gpm (Kahn 9/13 at 24). Some 25,000 acres of non-federal lands were located above the quantification points, compared to 71,000 acres of federal land (Rice 9/13 at 37-43; Blaue 9/13 at 67-71). Some 96% of the private, state and mineral patents were made before the National Forests were reserved (Rice 9/13 at 50).

The Left Hand Ditch on the South St. Vrain was originally constructed in 1863 and enlarged in 1970. Brand analyzed diversion data from 1955-1973 and estimated that 86.6% of the flow was being diverted on average. He believed in some years the whole flow had probably been diverted. The South St. Vrain USGS gage was located downstream, below a point where a major tributary entered the South St. Vrain. At the gaging station, the Left Hand diversions represented only about 46% of the flows (9/13 at 52-62; 9/14 at 6). The Left Hand Ditch actually had decrees senior to the U.S. claims (1863 and 1870). The rights were for more water than the ditch could currently carry, meaning more could be diverted in the future even if the U.S. claims were granted (11/19 at 5-12).

Silvey showed a video to illustrate that the South St. Vrain Creek channel downstream of the Left Hand diversion had adjusted to the lower flow regime over 120 years by creating a new active channel within the older channel. He called it "intermittently" or "partially" maintained (11/15 at 64-70). Silvey had used Brand's data to estimate that bypass flows averaged 13% of the annual flow on average, but could go up to 200 cfs or more, compared to the U.S. bankfull claim of 503 cfs (11/15 at 42-51, 66-67; 11/19 at 19-28). He had not made any measurements of channel capacity, but said it appeared to him that the Left Hand Ditch had the same capacity as the channel above the diversion (11/15 at 119-120).

Silvey's video illustrated the effect of intermittently high flows on a channel with a reduced capacity. These effects included sediment deposition in the area between new and old bankfull levels and erosion of existing active banks. Silvey said this showed what would happen in other diverted streams. When large flows were returned to a filled-in channel, the stream would attempt to regain its former shape. Streamflows were therefore necessary to maintain the channel system (11/15 at 97-112).

The U.S.'s estimated bankfull discharge was 180 cfs upstream of the diversion, but only about 13 cfs downstream. Andrews said if the 1989 claim had been in effect, the downstream channel would have had a bankfull capacity of about 120 to 130 cfs—about 10 times larger than the existing channel which didn't have channel maintenance flows (12/11 at 28).

A quantification point was located much further down on the South St. Vrain. At this site, the bankfull estimate was 503 cfs. Brand discussed the U.S. bankfull estimates by comparing the North and South St. Vrain Rivers. Approximately 40% of the flow came from the south fork and 60% from the north. Slopes were similar, but cross-sectional areas were 103.5 and 59.4 square feet for the South and North forks, respectively. The bankfull claim for the north fork was only 265 cfs. Brand said it didn't make sense for the north fork to have a smaller cross-sectional area and bankfull flow because it had more water and a flatter slope (9/13 at 50-52).

Kahn also brought out that the U.S.'s estimate of bankfull discharge at the South St. Vrain quantification point was only 138.8 cfs in the 1984 application, but had been raised to 503 cfs by 1989. Silvey explained that not all of the bankfull cross-sections had been measured in 1984, and that those claims had been based on a relationship between bankfull discharge and drainage area rather than the more data intensive 1989 procedure (2/1 at 136-138; 2/5 at 12).

During Silvey's testimony, it came out that the flows going into the Left Hand Ditch had not been subtracted from the total annual yield for the quantification point. This gave a very long duration for the bankfull, rise and recession components.

Stuart agreed that the data should be re-analyzed for that point. He also recommended re-evaluation of two other points below the diversion (2/1 at 138-139; 2/5 at 12; 2/6 at 118, 173).

Brand superimposed the U.S. claims on actual streamflow records for the South St. Vrain. He demonstrated that the hydrograph for this stream had two typical runoff peaks: one was a "false peak" from snowmelt below 10,000 feet and the second came later from snowmelt at higher elevations in June (fig. 23). Brand said the best place to build reservoirs was in mountain canyons in the foothills below 10,000 feet so both peaks could be stored. He demonstrated that the U.S. claims would often call out all of the water between the false peak and the normal peak. He also showed that an average hydrograph constructed from 4 years of record did not look like any of the individual yearly hydrographs. The average hydrograph showed the June peak but not the "false" early peaks which were more unpredictable (9/13 at 45-48).

Brand concluded that there was something wrong with the U.S.'s quantification methodology and that it wasn't achieving the U.S.'s goals. The claims never coincided with the peak of the river, so they never got bankfull flow. It was also his opinion that the bankfull flow claim of 503 cfs on the South St. Vrain would rarely occur (9/13 at 45-48).

Brand did not believe forest streams would be dried up by future diversions because there were so many downstream calls. There were also Colorado Water Conservation Board instream flows on many of the streams. He gave examples of how these claims were structured. For the South St. Vrain, a pending claim would leave 20 cfs in the stream from April-September, 12 cfs during October and November, and 4 cfs from December-March. This was much less than the U.S.'s claim (9/13 at 91-92).

Walch asked Brand what he thought of the idea of working some flexibility into the U.S. claims; e.g. by setting a higher "triggering" flow to begin the claim of 100 or 200 cfs instead of 50 cfs. The judge said this was a different claim than what the U.S. had applied for (9/14 at 49-55).

Section 8.
The 1990 Alternative Quantification Procedure

OVERVIEW

Legal Arguments

The U.S. did not attempt to directly address the opposition's criticism of its claim methodology in its rebuttal case. Instead, U.S. experts developed an entirely new quantification procedure and asked the judge to approve an amendment of the instream flow claims based on the new 1990 methodology. The new procedure would match claims to actual flows better and would therefore eliminate the "unexpected, unnecessary injury" which Altenhofen said would occur with the 1989 claims. It also reduced a significant number of the bankfull values (10/31 at 7-9).

The opposers vehemently objected to the 1990 amended claims, saying the U.S. had already presented a lengthy case in support of the original quantification procedures, and that they were now turning around and saying these procedures were wrong. Weiss argued that "this case is not a perpetual forum for them to develop science," and said if the U.S. couldn't rebut Altenhofen's testimony, they should dismiss their case. The trial had already been enormously expensive for the opposers, and they objected to trying a brand new case on the 1990 procedure and claims (10/31 at 12-49).

Walch argued that the new procedure was only a "simple modification," that it would make claims easier to administer, and that the basic theory of providing channel maintenance flows up to and including bankfull discharge remained the same. He said the U.S. was dealing with "a difficult, technical, scientific procedure that admittedly the Forest Service has had some difficulties with," and that they shouldn't be faulted for developing an improved method for maintaining streams which took Altenhofen's comments into consideration (10/31 at 49-56).

The judge allowed the U.S. to present testimony on the new procedure. He said if the new application represented a substantial departure from the original evidence presented by the U.S., he probably would not allow the application. The judge also said if U.S. witnesses testified that the 1989 application was wrong and the 1990 version was better—and if he then didn't allow the 1990 amendment—that he would have grounds for denying the application because it would appear that the U.S. disagreed with its own proposal. It was his impression that the U.S. had "essentially disowned its initial application" (11/28 at 5-8; 12/7 at 5-13).

Walch initially said the 1989 claim was not being abandoned, but later said if the 1990 amendment was granted, the 1989 application would be abandoned. He argued that the purpose of publishing a claim was to provide notice to potentially affected water users about what could be "reasonably calculated or claimed by the applicant," but not the exact amount. The Forest Service had stated that its intent was to obtain bankfull discharge, a portion of the rise-recession flow, and a minimum base flow. Walch said the purposes of the claim hadn't changed, and the 1990 claim would "do a better job of fulfilling the needs of the Forest Service without injury to the other water users" (12/4 at 170-178; 12/13 at 5-12).

The judge allowed the U.S. to present evidence on the 1990 procedure because it would help him reach a decision on the question of the new amendment. He also said that whatever decision he reached in the case, it would "no doubt be appealed," and having the evidence in the record would be of assistance to the appellate court (12/4 at 150-154).

Defense of the 1989 Claims

Channel Maintenance Capabilities

Andrews had examined Altenhofen's flow duration tables for the USGS stations, and agreed that the 1989 claims frequently missed the bankfull discharge. However, they did obtain some periods of high flows. Andrews said if those flows were left in the channel, it would adjust to this regime. He argued that even though the claims didn't exactly meet the U.S.'s objectives, they were "not in a sense worthless claims to maintaining some capacity of the channel." For example, at Boulder Creek, roughly 70% of the existing bankfull flow would be obtained on average. In high-flow years when this increased to 90%, the claim was more effective. Andrews stated that even though only 70% of the flow was being obtained, it would maintain a bankfull channel greater than 70% of the original capacity because of the effect of higher flow years (12/11 at 25-28).

Andrews also admitted that he had realized prior to his original testimony that there was a mismatch between the 1989 claims and the actual flow in terms of when the period of peak runoff could be claimed (12/11 at 94-96). Trout brought out that Andrews had discussed this with the same people who eventually developed the 1990 claim as early as March, 1989. He said the U.S. had stayed with the 1989 claims despite knowing these limitations (12/11 at 106-109).

Discussion of Hydrologic Similarity

Altenhofen had asserted that there were several reasons why the gaging stations weren't hydrologically similar to the quantification points, and therefore parameters such as bankfull duration couldn't be extrapolated from one to the other. To demonstrate hydrologic similarity Troendle presented data from 3 watersheds on the Fraser Experimental Forest with drainage areas from 1.1 to 33 square miles, first to fourth order streams, and different aspects. Records dated back to the 1940's. After "normalizing" the average hydrographs for the watersheds by dividing cfs by watershed area (CSM = cfs per square mile), Troendle concluded that the shapes were similar and "one could predict the flow from either of the other two by having adequate information about one of them." Flow duration curves were also similar (11/28 at 117-135). Maxwell had calculated the Qa/Qb ratios for these sites which ranged from 0.1 to 0.23 (12/10 at 14-16).

Troendle also discussed the hydrologic effects of clear-cutting. Studies at Wagon Wheel Gap, Colorado indicated that clear cutting of a watershed had caused a significant increase in the peak flow but did not cause a change in timing. On Fool Creek in the Fraser Experimental Forest, 40% of the area was clear-cut on east and west-facing slopes, and the time to peak was advanced by about 8 days. On Dead Horse Creek, 33% of a south-facing slope was clear cut; the timing of the peak did not change, although peak flows increased. Weiss then asked if this research meant that "preserving timber is no longer necessary to secure favorable conditions of flow?" Troendle said the trees did make a difference because by harvesting trees, they had the opportunity to increase the total volume of streamflow. Peak flows could be increased 20-50% and durations of higher flows increased. Timing of peaks was more unpredictable (12/3 at 109-113).

Maxwell gave another example of hydrologic similarity to disprove Altenhofen's allegations. He showed average hydrographs and flow duration curves from May to September for four "nested" watersheds in the Cache La Poudre drainage. These had been normalized by dividing by the average flow. The hydrographs and flow duration curves for the four stations were very similar even though drainage areas ranged from 92.4 to less than 1 square mile, and mean elevations varied from 9700 feet to 11,100 feet. The direction of drainage ranged from northerly to southeast. Maxwell concluded that these watersheds, as well as Troendle's set of watersheds, were hydrologically similar in terms of runoff patterns. The fact that one hydrograph peaked sooner or later than another didn't matter because the timing of the peak flows wasn't being extrapolated—only the flow durations. He pointed out that at the low-flow end of the flow duration curves (about 0.2 x average flow), there was some deviation; however, it was small and within the measurement accuracy range of the USGS gaging stations (12/3 at 160-171; 12/4 at 10-13, 22-23).

Even though Maxwell concluded that the basins were hydrologically similar, he pointed out the fact that the duration of bankfull discharge varied from 3 to 16 days. He argued that bankfull flow durations would only be the same (or within plus or minus one day, a criteria used by Altenhofen) if the watersheds were virtually **identical**, not just similar. He said, "no two watersheds are that much alike." In his experience, two things had the most influence on runoff patterns (12/4 at 31-33):

- the general climatic regime (e.g.. snowmelt vs. rainfall),
- watershed geomorphology (which included geology and topography).

Weiss later asked Maxwell to read off the percentages of mean annual water yield for bankfull, etc. For these four streams which Maxwell had said were hydrologically similar, percentages ranged as follows:

- bankfull: 6.1 to 23.1 %,
- rise/recession:18.2 to 34.5 %,
- base flow: 9.1 to 15.1 %.

Maxwell agreed that these varied substantially, but said it wasn't surprising (12/5 at 158-164). He also made the statement that the Qa/Qb ratio had to be used with caution (12/10 at 67-71). His purpose in showing the curves was to demonstrate that watersheds could still have flow duration curves with similar shapes even though they had different aspects, elevations, etc. (12/6 at 117-119).

Other Arguments

Other statements in defense of the original procedures were made by U.S. witnesses during their testimony on the 1990 methodology. They defended methods such as extrapolation, regression equations, and the use of mean daily flows rather than instantaneous flows.

Throughout the entire trial, U.S. experts were required to defend the fact that hydrologic data contained considerable scatter and that predictions of streamflow and sediment transport contained a degree of uncertainty. Rosgen had said, "there isn't anything that is absolute when you are dealing with rivers and measurement" (2/12 at 17). During Silvey's testimony, the judge asked in reference to the claims, "so you are really not sure . . . how close that is to reality?" Silvey said "how close" could only be determined by on-site measurements (2/1 at 88).

The opposition argued that on-site measurements or at least improved stream gage measurements should have been used to more precisely define the channel maintenance flows. Andrews addressed this by saying even 5 years of data at a site wouldn't be enough because this wasn't "as good as a regional relationship based upon 15 or 20 years of record at many different gages." To know the mean annual flow at a site to plus or minus 10% would require roughly 12-15 years of record for the Colorado mountain streams. It currently cost about $10,000 per year to run a gaging station—or about $40 million for 15 years of data at the 232 QPs. For 5% accuracy, about 20-25 years of data would be required, at an even higher cost. Andrews said, "precise hydrologic information is very expensive—both in terms of dollars and time." He considered Colorado relatively well gaged. He said in hydrology, it was typical to accept a certain level of uncertainty, and extrapolation was a very common procedure. There was always a tradeoff between precision and cost (12/11 at 5-10, 18-22; 2/20 at 20).

Leopold defended the use of judgement in interpreting the results of calculations, saying "in many cases the engineering judgement is actually more sound than simply relying on just any computation" (1/25 at 20, 99). Even Simons, an opposition witness, said it was important to realize that the scatter in river data represented "real conditions that occurred in the stream." He said when designing bridges and dams that he wanted to accommodate this variability rather than using an average value. As an example, he said the relationship between Manning's n and discharge had scatter. When designing for flood control, he might pick an "n" value which gave the largest depth (large n), whereas for designing rip rap, he might pick an "n" value that gave the largest velocity (small n) (4/11 at 72-73).

Harvey had made a statement about not extrapolating beyond one's data base, i.e. from plains to mountain streams. When Harvey later said something about the principles of fluvial geomorphology just being Newtonian physics and occasionally non-Newtonian, Walch turned this argument around by saying that the data base that Newton used was an apple and the fundamental tenets of extrapolation might be violated if there weren't any apples up in WD1 (4/5 at 63, 162).

In the 1990 claim methodology, a systematic procedure was developed for selecting bankfull discharge which eliminated the use of judgement. Extrapolation procedures were made more consistent and regression equations were refined using statistical packages which produced confidence limits. The opposition continued to argue that the U.S.'s methods did not necessarily result in the minimum amount and did not specifically relate to sediment transport at the individual quantification points. The U.S. was therefore unable to define the precise quantity of water necessary to maintain the stream channels. They also argued that the 1990 procedure could take more water in some years than the 1989 procedure.

Developing a New Approach

In late 1990, after Altenhofen's testimony, the U.S. formed a team of experts of which Maxwell was team leader. The team included Leopold, Andrews, Dawdy, Rosgen, Silvey and several Forest Service hydrologists. The judge noted that there were no botanists or plant ecologists on the team (12/4 at 148-150; 12/7 at 30-31).

Maxwell said there were two principal issues raised by the objectors which were of concern:

- prediction of bankfull discharge at quantification points,
- matching of the claimed hydrograph with the actual hydrograph on a year-by-year basis.

The U.S. experts admitted that in many years the 1989 claims would fail to achieve bankfull discharge. They also wanted to address the potential for injury to upstream junior water users. The goal of the new team was to conduct a "wholesale review" of the quality of the Forest Service's procedures, analyses and data. The purpose was to come up with the best approach for this and future cases involving cally, they wanted to develop a method of claiming the **minimum amount of water needed to maintain channels** while reducing the potential for injury to upstream junior water rights "to the lowest practical level." (12/4 at 148-150; 12/3 at 151-153, 157-159).

Maxwell believed the 1990 claims would meet these goals and that they were "fair and reasonable." The team also recommended that Chapter 30 should be revised to include the recently developed information and procedures (12/5 at 122-123; 12/10 at 61).

During his testimony, Maxwell made a statement that the static nature of the 1989 claim injured junior water rights and prevented the Forest Service from getting bankfull and rise/recession flows most of the time. At about this point, the judge expressed a certain amount of exasperation with the U.S.'s case. He said that they had testimony from all these fluvial geomorphologists of national and international fame, and a witness with a few honorary degrees but not an academic Ph.D., and asked Maxwell:

> *"isn't it surprising that somebody didn't notice, these internationally famous people didn't notice these defects in the application before it was presented to this Court for over a period of several months? . . . Do you have an explanation of why this was presented in an incomplete manner to begin with? . . . And particularly after the fact that this Court, year after year after year at term day, over objections, substantial objections, from the objectors continued the matter so that the matter could be completed; how am I to understand that after all those years of completion, in three months the whole thing can suddenly be corrected? Do you have any explanation for all that? I may be asking you a question that is impossible to explain." (12/5 at 137-138).*

Maxwell responded by saying that Altenhofen and other opposition witnesses had raised some valid points. The U.S.'s experts had then dug into the issues to look at them in a "very concerted effort as a team." The judge then asked if they hadn't been doing this for the 14 years that the application had been pending. Maxwell said the mobilization of a "couple of dozen people" with the sole task of going over the claims with a fine-tooth comb hadn't been done before (12/5 at 139-140).

The judge also made this comment about the 1990 procedure:

> *"so, if this had been presented in the original case, I imagine we would have had a much, much shorter case . . . several months" (12/5 at 62).*

THE 1990 CLAIM METHODOLOGY

Structure of the Claim

Maxwell said the 1990 claim was basically the same as the original one "in nature." A bankfull discharge, base flow and rise/recession component were still being quantified and claimed. The mechanism by which the claim would rise from base flow to bankfull and back again had been changed. In the original method, the claim was triggered when the actual streamflow reached mean annual flow and stayed at it or above for 2 days in a row. That concept was "still implicit in this claim," in that mean annual flow was the "triggering device." However, the mechanism for fitting the claim to the actual streamflow hydrograph at a quantification point had changed to make it more flexible. Procedures for computing bankfull and base flows had also been refined (12/4 at 155-156).

The 1990 claim mechanism broke the instream hydrograph into four phases (Maxwell 12/5 at 18-31):

1. When the actual streamflow (Qs) was less than the computed base flow (Ql), all of the flow would be claimed.
2. When the streamflow equaled or exceeded the base flow but was less than mean annual discharge (Qa), the base flow amount was claimed.
3. When the streamflow reached mean annual flow but was less than bankfull (Qb), then a percentage of the streamflow above base flow was claimed.
4. When the streamflow was equal to or greater than bankfull, bankfull was claimed. Water users could have anything exceeding bankfull.

The 1990 claim would increase to bankfull and drop down again as a smooth line. It always remained below the actual streamflow hydrograph. This contrasted with the 1989 claim which had a "stairstep" appearance and was constructed the same for all years, regardless of actual flows (Maxwell 12/4 at 156-166). The 1990 claim hydrograph was called a "dynamic" hydrograph because it rose and fell with the natural streamflows, as opposed to the "static" 1989 claim. Figure 24 shows how the 1990 claim looked when superimposed on an actual hydrograph. It can be compared to Figure 23 which shows the 1989 claim.

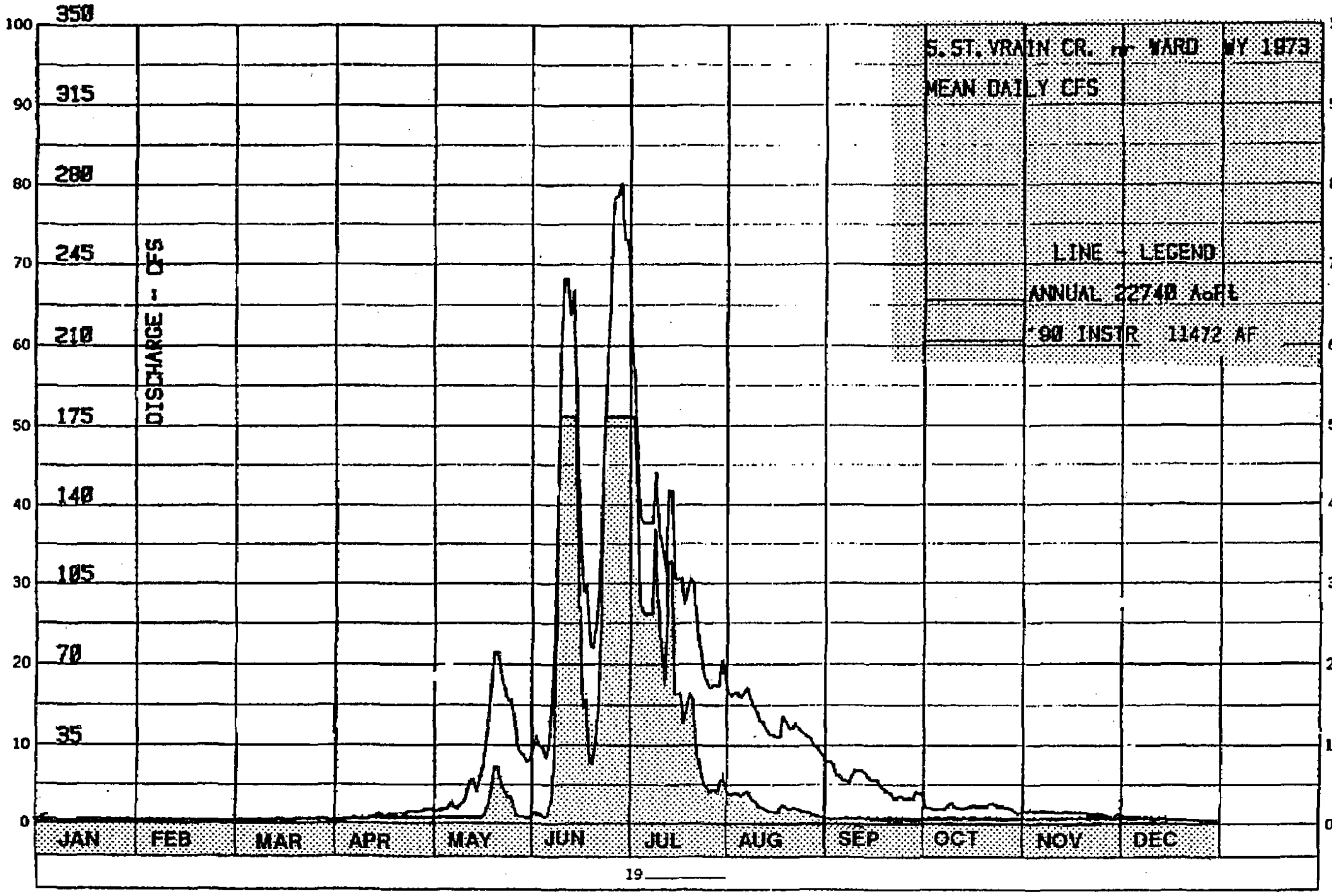


Figure 24.—Streamflow hydrograph for the South St. Vrain gaging station with the 1990 claim superimposed. From Exhibit [A-1619].

Computing Water Yield at the Quantification Points

The New North-South Equation

Altenhofen had testified that the Forest Service's procedure of extrapolating water yields from USGS gaging stations to quantification points (QPs) was inappropriate. Troendle was asked to look at this procedure. The 1989 "North" and "South" equations had been developed by fitting nonlinear regression equations to USGS data, which could then be used to predict water yield as a function of elevation (11/28 at 77-86).

The North and South equations were refined by including additional years of data collected in the interim. Four of the watersheds only had four years of record at the time the original equations were derived, and this was increased to at least 8 years for the new equations. All 20 of the original USGS stations were apparently included, although the Plum Creek station was moved from north to south. The original equations had been fitted through data points representing mean annual water yields for each station. The new equations were fitted through the individual yearly values, which could number 8 for one station and 60 for another (11/28 at 86-96, 103-108; 12/3 at 59-71). [**Author's note**: this procedure would tend to over-weight the stations with longer records].

The new and old regression lines paralleled each other and agreed fairly well. Confidence bands at 95% were also developed for the new equations. R^2 values were 0.96 and 0.99 for the new north and south equations, respectively. The new south equation deviated from the old one at higher elevations (11/18 at 98-102). Weiss asked for the mean standard error of the north-south equations, which Troendle did not have (12/3 at 88-89).

Troendle defended the use of a regression line which indicated an average trend. The scatter of data points to either side of it defined a probability distribution around that average line. Points a long distance away from the line had a lower probability of occurrence (11/28 at 108-113; 12/3 at 59-71). Weiss inferred that any time the equations overpredicted runoff, it would mean injury to water users; i.e. the Forest Service was taking more water than the minimum they were entitled to. Troendle said that by taking the mean, there would be a certain number of predictions above the actual amount and a certain number below it. For an ungaged site, they would be correct more often by using the mean (12/3 at 94-98).

Troendle had also analyzed the effect of including other factors such as latitude and longitude in the regression equations, but concluded that the equations which just used elevation could predict water yield "reasonably well" (11/28 at 108-113). Maxwell addressed this same issue by referring to a 1985 USGS paper by Kircher et al, on estimation of streamflow in Western Colorado. The USGS had analyzed the influence of a large number of physiographic, climatic, vegetation and land use characteristics on streamflow. They concluded that drainage area and mean basin elevation were the best factors for estimating average annual runoff in ungaged watersheds (12/4 at 44-50, 55).

The judge asked Troendle why the U.S. needed two formulas (north and south) if the only important factor was elevation? Troendle said that the northern areas received more precipitation than the south and therefore elevation played a slightly different role (11/28 at 159-160). He didn't know of any other way the Forest Service could have approached this predication because the quantification points were relatively remote and adequate precipitation and runoff information didn't exist (11/28 at 117-125).

Weiss referred to one of the equations to demonstrate that it would predict a value of 1.1 feet of water yield for an elevation of 10,000 feet—with 95% confidence that the true water yield would be anywhere between 0.3 and 2 feet. This could mean a substantial difference in the amount of water claimed (11/28 at 114-117). Troendle agreed that there were discrepancies caused by extrapolating data to quantification points, but that the average regression line provided the best estimate. He also said the USGS records themselves could contain measurement errors on the order of 5-15% (12/3 at 72-79).

In regard to the south equation, the difference between the old and new versions of the equation amounted to a 13% change at a mean basin elevation of about 11,250 feet. For one quantification point with a 47,809 acre drainage area the change in the equation resulted in an increase in the estimated water yield of 5700 acre-feet per year (12/3 at 86-88).

Reassignment of Quantification Points

Some QPs had apparently been reassigned to the north equation from the south and visa-versa. Weiss criticized this, asking whether the 1989 procedures were wrong. Maxwell said the changes were a refinement. Weiss then pointed out that the south equation predicted a lower water yield than the north, and for those stations reassigned from north to south, the 1989 procedure would have overpredicted yield. Maxwell said there were sound physical reasons for reassigning the QPs, and that the only way to really tell if equations predicted correctly was to test them against actual water yield data. Weiss said, "I would certainly agree; the best thing would be to have actual water yield data at those quantification points" (12/6 at 48-49).

Extrapolation to Quantification Points

In the 1989 methodology, mean annual discharge was extrapolated from the base station to the QPs as part of a "block" of water calculated from flow duration curves. In the 1990 methodology, the new North and South equations were used to estimate both the water yield and mean annual discharge for the quantification points (QPs) (12/5 at 43-46).

Streamflow patterns were again extrapolated from USGS gaging stations to quantification points. However, in the 1990 methodology, quantification points were no longer assigned to a specific base station. They were grouped to correspond to 3 "families" of USGS base stations, for which flow duration curves had similar patterns. For this grouping, 4 out of the original 20 USGS stations were removed because of reservoir influences or very short periods of record: Jefferson Creek, Michigan Creek, Tarryall Creek and North Fork Michigan River. The three groupings were:

- north high elevation stations,
- south high elevation stations,
- low elevation stations.

Maxwell said the 3 families of curves had distinctive shapes. The low-elevation curves were very steep and dropped off to a low level, indicating that these watersheds had a more flashy type of runoff response. The patterns for the low-elevation sites were also much more erratic from year to year. The higher-elevation north and south curves were flatter, S-shaped, and stayed at a higher level at the low end. North and south curves were separated because the northern region tended to receive more precipitation. The south high-elevation sites were intermediate in variability, and the north high-elevation sites had a more dependable, predictable supply for diversion. The northern region was also the area where most of the potential conflicts with other water users might occur. The improved predictability would make it easier to plan and to quantify water rights (Maxwell 12/4 at 35-39, 162-163; 12/5 at 11-13, 55-58).

The assignment of QPs to the 3 families of base stations was based on the judgement of forest hydrologists. They considered elevation, the influence of rainfall and snowmelt, and also whether the QP stream had seasonal or perennial flows. The dividing line between low and high elevation sites was roughly a mean elevation of 7500 to 8500 feet, but forest hydrologists were given some latitude based on knowledge of local topography, forest conditions, etc. For the base stations, the range of mean basin elevations were (12/7 at 20-21; 12/5 at 58-60):

- north high-elevation stations: 9700 to 11,100 feet,
- south high-elevation stations: 8900 to 11,800 feet,
- low elevation stations: 6900 to 8200 feet.

Walch submitted an exhibit showing a three-dimensional plot of streamflow for the base stations for the periods of record. About 80% of the flow occurred between October and the middle of July for most stations, indicating that these were snowmelt-dominated streams. The use of the July-October period as rainfall-influenced was considered conservative. Cherry Creek was the only one of all of the 20 base stations that Maxwell said was not clearly snowmelt-dominated, although snowmelt still had an important influence on its hydrograph. He called it a "mixed situation." Maxwell hadn't checked rainfall records, and did not know if more rain occurred before July than snowmelt in July-October (12/10 at 17-29).

Harvey had earlier discussed some of the work done on mountain streams by Costa, Jarrett and Pitlick of the USGS. Their work indicated that on the Front Range, the channels experienced two types of flood regimes, where an elevation of 7500 feet represented a "cutoff" between snowmelt-dominated flood regimes and rainfall-dominated flood regimes. They developed two regional flood frequency curves (flood discharge/mean annual flood vs. return period), one for the alpine zone above 7500 feet and the other for the Colorado foothills below 7500 feet. As an example, the 50-year flood was less than 2 times the mean annual flood in the alpine zone, but 7-8 times the mean annual flood in the foothill zone. Harvey said this meant the channel morphologies would differ because of the different flood patterns (4/2 at 585-587).

Maxwell mentioned that a snowstorm had occurred last September in the Denver area, and that warm weather over succeeding days led to snowmelt-induced runoff. However, he said that by looking at the hydrograph, it might have looked like a rain-induced event. Trout asked him if he would distinguish between "snow that falls on Monday and melts on Tuesday" and "snow that accumulates in the mountains all winter and melts in the spring," in terms of their effects on the hydrograph. Maxwell said both were snowmelt processes—they only differed in terms of scale. Trout was attempting to get Maxwell to define the term "snowmelt-dominated." Maxwell made a vague reference to a "50% effect," and said it wouldn't be surprising to find a "reasonably strong influence of snowmelt" on essentially all streamflow records in Colorado (12/6 at 112-116).

Troendle said the cutoff between subalpine and montane zones was about 8000 to 8500 feet in terms of vegetation differences, but in terms of hydrologic response, the cutoff was about 7500 feet between rainfall-influenced and snowmelt-driven flood peaks (12/3 at 11). He agreed with a statement by Trout that in the subalpine zone, only 3% of summer storm precipitation got back to the streams as runoff, and 10% or less of the total yearly water yield came from rainfall (12/3 at 53-56).

Trout brought out that the low-elevation "family" had been used for extrapolation to three QPs with mean basin elevations over 8500 feet. Maxwell defended this action, saying that a high elevation stream could dry up for a portion of the year, and in that case it was more appropriate to relate it to the low-elevation curves (12/6 at 120-124).

Troendle said if data from a gaging station, even from a larger, lower-elevation area, were the only information available, "then the alternative is a guess"—so the data were "better than having nothing at all." Trout asked whether putting a gage in an ungaged basin to obtain a flow duration curve would be better. Troendle said yes, but also said the cost would be higher and it would take 5-20 years to collect enough data (12/3 at 9-10).

Computing Bankfull Discharge

In the 1990 procedures for computing bankfull discharge, the two Leopold equations were retained but the Limerinos and WD1 equations were replaced with Manning's equation and a "velocity equation" developed by Troendle. The latter was used as a "reality check" on the results of the other equations, and as a "default" equation if the others gave unacceptable values.

The Troendle Velocity Equation

The U.S.'s methods for calculating bankfull flow had been severely criticized by the opposition, particularly their reliance on the "WD1 equation" which basically gave a bankfull velocity of about 4 ft/sec at all sites. Troendle agreed that it would overestimate bankfull discharge for smaller watersheds which often had A2-type streams. He said the bankfull velocities in step-pool systems reported in the literature were close to 2 feet per second. A Forest Service researcher, Heede, had taken measurements at the Fraser Experimental Forest and had found bankfull velocities from 1.76 to 2.5 ft/sec (11/29 at 110-114). Leaf (8/2 at 101-104) had earlier said velocities in step-pool systems were on the order of 2 ft/sec.

Troendle developed a new equation, the "velocity equation," based on an estimated bankfull velocity times the field-measured bankfull cross-sectional area. To calculate velocity, he analyzed the relationship between stream velocity and watershed size using data from the 20 base USGS stations, 4 of the USFS fluvial sites and 3 Fraser Experimental Forest stations (fig. 25). These 27 data points represented watersheds of 300-200,000 acres in size. The points appeared to describe two patterns, so Troendle fit two linear segments to the data with a break at about 17,000 acres.

At 10,000 acres, the 96% confidence lines spanned a range from 1.5 to 4.5 ft/sec; there was therefore quite a bit of variability in the limited data set. For watersheds above 17,000 acres in size, the regression line gave a constant velocity of 4.37 ft/sec (plus or minus 0.82) (11/29 at 41-58, 131). Weiss brought out that there were six A2-type streams used in developing the velocity relationship, of which 3 had bankfull velocities greater than 3 ft/sec (11/29 at 61-62). The judge asked if it was just a coincidence that the WD1 equation gave a velocity of about 4 ft/sec and Troendle's velocity relationship gave a velocity of 4.4 ft/sec. Troendle said they were based on the same data (12/3 at 131-132). Trout made the argument that one of the criteria used in selecting a bankfull estimate was that the velocity shouldn't exceed 5.5 ft/sec. Troendle's velocity equation didn't really support this except at a drainage area of about 15,000 acres (11/29 at 127).

In cross-examination, Trout brought out that the R^2 value for the sloping part of the velocity equation regression line was only about 0.65. Since the R^2 coefficient on the WD1 equation was greater than 0.9, Trout suggested that it was actually a better approach (11/29 at 131-136). He also pointed out that Troendle had not used the Goose Creek gage, meaning he had only used 19 of the USGS stations. Troendle said the cross-sectional area at that station had been questioned. Its bankfull velocity was 2.97 ft/sec, which was lower than for comparable data points (11/29 at 119-124).

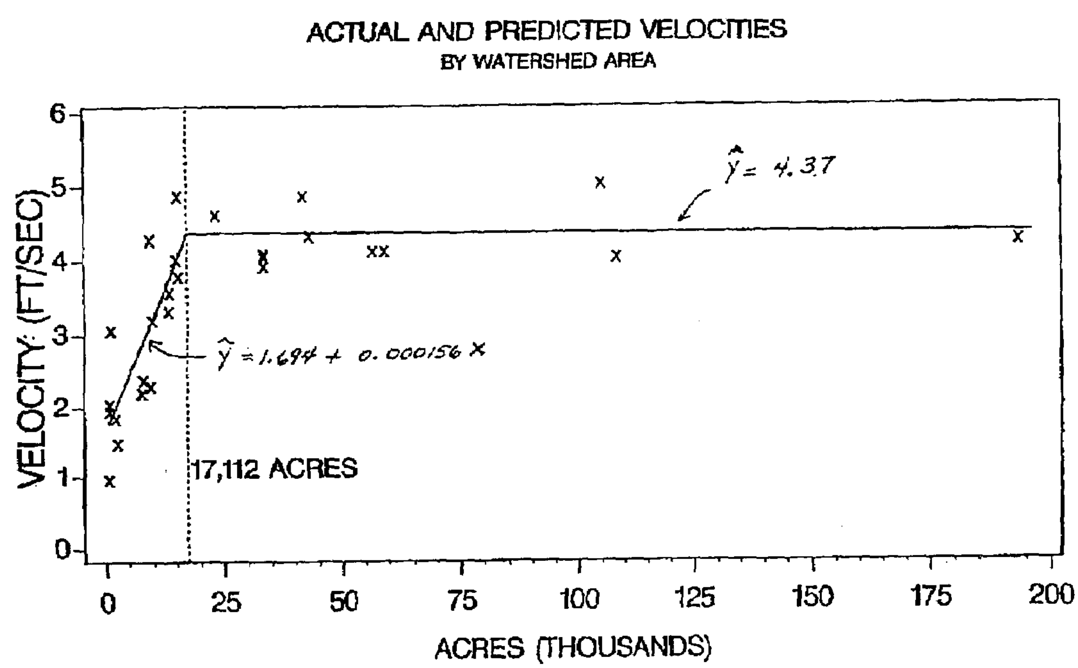


Figure 25.—The "Troendle velocity equation," fit to data from 20 USGS base stations, 4 USFS fluvial sites and 3 Fraser Experimental Forest sites. From Exhibit [A-1444].

Troendle had calculated the 1.5-year flow for the Fraser gaging stations (11/28 at 167-176). Return periods for the field-estimated bankfull flows using a velocity x cross-sectional area estimate ranged from 1.2 to 1.9 years, indicating good agreement (11/28 at 176-180). He also posed a rather lengthy argument to illustrate that even though an average daily flow or an average hydrograph didn't reach bankfull, that instantaneous values could. In fact, bankfull flow could occur twice in the same year as a "double peak" (11/28 at 180-188; 11/29 at 30-37).

Troendle concluded by saying that his velocity relationship wasn't developed in order to come up with a new, substitute equation. It was meant to be used as a check after bankfull discharge had been computed by some other method, to see if the calculated velocity was reasonable (11/29 at 58-60). He had gone back and computed bankfull velocities for the 20 USGS base stations using his relationship. When these estimates were plotted against measured bankfull flows at those sites, the points plotted close to a 1:1 line (12/3 at 133-136). Troendle agreed that his graph didn't give any information about velocities outside the data base (12/3 at 137-139).

Trout later criticized the fact that several QPs had different stream types (C-6, B-3, B-6 and A-3) than at the USGS base stations. Trout said those stream types were not represented in the data base for the velocity equation, yet this equation was used to estimate bankfull flow at those sites (12/10 at 97-98).

Manning's Equation

Manning's equation had been used by engineers and hydrologists for decades as a method of estimating streamflow from hydraulic measurements (Maxwell, 12/10 at 64-65). In English units, it could be written as:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

with V = velocity
R = hydraulic radius
S = slope
n = "Manning's n" roughness coefficient.

Manning's n could be estimated or it could be back-calculated if measurements of velocity were available. The U.S.'s review team used four sets of data to develop bankfull "n" values by stream type: the USGS base station data, the 3 Fraser gages, 5 fluvial sites where measurements were taken very close to bankfull, and a set of Manning's n values at bankfull provided by Rosgen. The data were stratified by Rosgen stream type and averaged to obtain the values in Table 4 (12/5 at 89-93).

Weiss mentioned that as Manning's n went up, velocity went down proportionately. For the A2 stream type, the "n" value was based on an average of 10 values which ranged from 0.073 to 0.504. For one example, the average "n" value gave a bankfull discharge of 35 cfs, whereas the bankfull discharge actually measured at the gage was 11.9 cfs. Maxwell defended the use of mean values for extrapolation to unknown points as "the scientifically most appropriate method" (12/6 at 5-17).

Table 4.—Manning's n values by Rosgen stream type used in the 1990 procedure for calculating bankfull discharge. From Exhibit [H-962].

A2:	0.171	B1-b:	0.048	B6:	0.080*	C4:	0.027*
A3:	0.063*	B2:	0.062	C1:	0.057	F3:	0.040
B1:	0.068	B2b:	0.040	C2:	0.038	F4:	0.049
B1-1:	0.051*	B3:	0.058*	C3:	0.032	F5:	0.036**

*based on one value provided by Rosgen
** based on two values " " "

Procedure for Selecting Bankfull Estimate

The method of selecting a bankfull estimate was standardized so each person would follow the same "road map" to obtain an answer. The stepwise criteria were as follows (12/5 at 74-77):

1. Check the **Leopold D_{84}** equation result. It would be used to calculate bankfull discharge if R/D_{84} exceeded 1.1 and predicted velocity was less than 5.5 ft/sec, as for the 1989 procedure. However, in the 1990 procedure, a "reality check" was added. The predicted velocity had to fall between the 95% confidence limits of Troendle's equation for this result to be accepted.
2. Check the **Leopold D_{50}** equation result if the D_{84} equation was not appropriate. The D_{50} criteria were the same as in 1989, again with the additional requirement that the predicted velocity had to fall between Troendle's 95% confidence limits.
3. If the above two equations weren't applicable, the third choice was **Manning's equation.** "Manning's n" values had been compiled by Rosgen stream type. Again, this result was only accepted if the predicted velocity fell within Troendle's 95% limits.
4. If all other equations failed, the "default" method was to use **Troendle's mean line** to predict bankfull velocity.

All of the above relationships were used to calculate bankfull velocity. This was a slightly different approach than the 1989 methodology, because the WD1 equation predicted bankfull discharge directly whereas the 3 other methods predicted velocity. The 1990 methods were therefore more consistent. Computed velocities were multiplied by cross-sectional areas at the quantification points to obtain bankfull discharge (12/5 at 77-78).

Slope entered into several of the bankfull equations. Maxwell said the forest hydrologists were instructed to review all of the data which had gone into the calculation of bankfull discharge, considering the location of the cross-section, channel features, etc. He mentioned that a few changes had been made to the basic data, including slope (12/5 at 131-137). Trout had pointed out that 12 slopes had been changed from 1989 to 1990 for the Arapahoe/Roosevelt quantification points. He suggested that local slopes were now being used in step-pool systems rather than overall reach slopes. For one Fraser site, the slope was 7.1% but a spreadsheet showed a slope of 17.4%. Troendle had said the latter was probably the "valley slope," whereas a local slope at the cross-section had been used in the calculation. Using the overall slope would have resulted in an overestimation of velocity and bankfull discharge (11/29 at 86-95; 12/3 at 16-19; 12/7 at 43-53). Trout also argued that a "local pebble count" would have been more appropriate for calculating velocity in step-pool systems using the Leopold equations (12/3 at 25-28).

Spreadsheets were developed for calculating bankfull discharge at a quantification point. These included the cross-section data, D_{50} and D_{84} values, stream type, and the selected bankfull equation and computed discharge. It also listed the equation selected using the 1989 methodology, and the percent change from 1989 to 1990. Separate spreadsheets were developed for the Arapahoe-Roosevelt and Pike National Forests (12/5 at 96-99).

Weiss summarized the number of times each equation was used (12/6 at 28-31):

Equation	Arapahoe-Roosevelt N.F.	Pike N.F.
LeopoldD_{84}	28	40
Leopold D_{50}	39	9
Manning's	24	25
Troendle velocity	38	31

There were now a total of 235 quantification points. Out of these, about half used either the Manning's or Troendle velocity equation. Troendle's equation was used about ¼ of the time (12/6 at 31; 12/3 at 28-32). At about 35 points, bankfull claims were larger than the 1989 values (Walch, 12/13 at 29-31, 121-122). Walch also mentioned that the Forest Service had made a policy decision that when bankfull discharge fell below 1 cfs, they would not make a claim for that quantification point— it would be dropped (12/5 at 112).

Maxwell, in addressing the variability of results from the 4 bankfull equations, said they were being allowed to operate within the observed variations on velocity represented by Troendle's relationship. That kind of variation was real; it was based on actual measurements. He showed a plot of the bankfull discharge estimates in cfs/square mile vs. mean basin elevation. The graph also showed the 1.01 and 3 year return flows at USGS base stations which represented the range of average recurrence intervals at those sites. As a whole, the bankfull discharge estimates for the quantification points plotted within this range. Based on this, Maxwell said that the bankfull estimates were "very reasonable" (12/5 at 99-102; 12/10 at 64-65).

The opposition pointed out a number of errors in the use of the selection criteria. For example, if no "Manning's n" value was available for a particular stream type, the spreadsheet program would default to a different "n" value. For example, no data were available for "A4" stream types, and when the computer encountered quantification points with this stream type, it defaulted to two different Manning's n values. Maxwell said these had later been corrected by using the Troendle equation instead (12/5 at 102-105; 12/6 at 21-27). Trout also criticized the fact that many of the Manning's n values in the data base were only based on one measurement. He argued that the only way to really obtain a correct value was to go to a QP and take enough data to calculate it on a site-specific basis (12/6 at 79-92).

The judge said the process of using Troendle's 95% confidence bands as a "reality check" was somewhat questionable to him because of the small number of data points used in developing that relationship. He said, "it leaves a lot of room for unusual figures to get in there." Maxwell said more points wouldn't necessarily reduce the scatter, and that they had to work with what they had (12/6 at 17-20).

The judge asked Andrews his opinion on the two Leopold equations, particularly Leopold's proposal that these could be used as long as the calculated velocity didn't exceed 5.5 ft/sec. Andrews said the formulas were developed using data over a certain range of measurements, and the relationships were most reliable within that range. The judge then asked why, if those equations were supposed to cover that range, that the Troendle equation was needed. It was his observation that Troendle had taken the data from a "very limited area on the Western Slope" and used it to reach "all kinds of far-reaching conclusions," including overriding what Leopold had said (12/11 at 11-15).

Trout presented statistics on how often the Leopold results were rejected. On the Arapahoe-

Roosevelt N.F., the Leopold equation was not used 62 times. Of those, 30 had been rejected because the computed velocity was outside the confidence limits of the velocity equation. On one additional occasion, the Leopold criteria were met but the velocity equation was chosen instead. In the Pike N.F., the Leopold result was rejected 56 times, and out of these, 34 times were when it failed the "Troendle test" (12/11 at 100-105).

Weiss asked if one way of checking the accepted Leopold results would be to compare them to the results from the other two equations. She pointed out one example where the D_{50} equation was selected, and it gave 22.55 cfs. For the same site, the Manning's equation gave 6.96 cfs and the Troendle equation gave 16.26 cfs. Other examples of this type showed that there were some large differences between the four results (12/6 at 31-38).[8]

Maxwell presented exhibits to show that the Qa/Qb ratios for the quantification points using the 1990 procedure showed little change from the 1989 distributions. Trout said there were actually more points outside Altenhofen's 0.04-0.22 range in 1990 (12/10 at 6-7).

Computation of Base flow

There was no change in the purposes for which base flow was claimed in the 1990 methodology. In the 1989 claims, a "block" of water representing the base flow volume was calculated at the base station and extrapolated to quantification points. In the 1990 procedure, base flows were also extrapolated from base stations to extrapolation points, but the extrapolation was made from the 3 "families" of base stations, and the procedure of defining base flow at the base stations differed.

The base flow at the gaging stations was determined from an inflection point on the flow duration curve, plotted on arithmetic axes (see Figure 22). Maxwell described the middle part of the curve as a "plateau" which dropped off on the low end. This was where the stream was basically starting to dry up. The U.S. review team was reasonably sure that this flow had a high probability of covering the low flow portion of the channel and was a good index of the minimum level of base flow necessary to transport sediment and prevent vegetation encroachment (12/5 at 48-55; 12/7 at 22-24).

Base flow at a quantification point was calculated by using a base flow: mean annual flow ratio (Ql/Qa) from the appropriate "family" of USGS base stations. The extrapolation was based on the assumption that the QPs were hydrologically similar to the associated family of base stations, meaning the Ql/Qa ratios could be extrapolated. Mean annual discharge, Qa, was computed using the improved North-South equations (Maxwell 12/5 at 60-61; 12/7 at 22-24).

Maxwell had looked at the ratio of base flow to mean annual flow for each family of curves. In the process, he identified two more stations which were dropped from the base flow analysis: one had a large number of springs just above the stream gage, giving a high base flow component, and the other one was located in a wide valley filled with alluvium which acted "like a big sponge" and released a lot of water as base flow. Maxwell said these were atypical conditions at the quantification points. The mean Ql/Qa ratios were:

- North high-elevation sites: 0.069
- South high-elevation sites: 0.096
- Low-elevation sites: 0.016

By comparison, the spring-fed site removed from the analysis had a ratio of 0.272 (12/5 at 55-58; Exhibit A-1615).

Weiss pointed out that one USGS base station dropped from the analysis of Ql/Qa ratios had still been used in the 1990 North or South equations. Both she and Trout claimed inconsistency because the USGS gages dropped from the 1990 base flow analysis had been used for extrapolating base flow percentages in the 1989 claims (12/6 at 41-45; 12/7 at 35-40).

Maxwell said several factors could have an influence on base flows, although they wouldn't necessarily affect mean annual flows. These included the depth and amount of valley alluvium, the geology, or the presence of springs, ponds and lakes. He believed the Ql/Qa ratio had a sound physical basis and provided a reasonable mean value for extrapolation (12/5 at 63-65).

Computed base flows ranged from 0.5% to 2% of bankfull discharge (Maxwell 12/5 at 46-50). Trout said base flow was very low on some streams; in some cases 89-99% of recorded flows exceeded that level. Maxwell said the 1990 claim was not necessarily intended to fill the low-flow channel. The 1989 claim apparently was (12/7 at 24-30, 32). An "administrative decision" had been made to not increase the magnitude of the base flow in the 1990 claim so it became higher than the 1989 claim (12/7 at 35-40). The base flow rate went down for about 75% of the quantification points (12/10 at 72).

[8] **Author's note**: *This will continue to be a valid criticism. There haven't been any good arguments based on reality for why the D_{50}, D_{84} and Manning's equations apply to different situations. Why use 4 equations?*

Several of the 1990 claims did not have a base flow component. At some sites, the 1990 base flow component essentially extended throughout the year, but involved very low values. There would be some days which would have had no base flow under the 1989 claims which would now have a base flow under the 1990 procedure. The judge clarified Maxwell's statements by saying, "if they can get it for the year, they will take it, but if they can't get it, they will forget it"—to which Walch and Maxwell both agreed (12/5 at 113-114).

The judge also asked what would be achieved by claiming such a small portion of the low flows—whether it was a wasted act, "or does the Forest Service think they have to do something, and better that than nothing?" Maxwell said they wanted to maintain the natural function of channels by preventing vegetation encroachment. He said if the streams were allowed to dry up, woody vegetation could move in. When high flows then returned, the water would be diverted against streambanks by the vegetation, causing erosion (12/5 at 10-11).

Rise/Recession Flows

Leopold developed the new procedure for computing rise/recession flows which was based on a proportion of the flow between base flow and the natural streamflow. This was calculated from the formula (12/5 at 27-31; Exhibit A-1618):

$$\text{Claimed flow} = Ql + \left((Qs - Ql) \times \left(\frac{Qs - Qa}{Qb - Qa} \right) \right)$$

Where: Qs = actual streamflow
Ql = baseflow
Qa = average annual flow
Qb = bankfull flow

This was the amount claimed when the actual streamflow was between mean annual flow and bankfull flow, and was used for both the rise and recession components. The judge at one point asked whether the sudden development of this formula was "an example of inspiration or desperation?" Maxwell answered inspiration (12/7 at 83-84).

Figure 26 shows how the 1990 claim compared to the 1989 claim on a flow duration curve.

ADMINISTRATION OF THE 1990 CLAIMS

The 1990 amended application listed each quantification point with its reservation date and claimed amounts for base flow, mean annual discharge and bankfull discharge. The U.S. was no longer claiming "blocks of water," or the steps rising up and down, or a specified duration of bankfull discharge. The language of the 1990 claim described how the actual claimed amount was established in any year (12/5 at 112, 114-122).

Trout argued that the formula for rise/recession claims was based on daily flows, so no one would know what the claim was until a particular day. Maxwell agreed, but explained that the claims could be administered quite easily through the use of weirs calibrated to the claim formula. Weirs would "slice the streamflow . . . into the divertible component and the claim component." The judge then asked whether all of those weirs would "screw up the streams more than they are already?" Maxwell said he didn't think so, and that there were weirs at the Fraser Experimental Forest (12/5 at 31-34; 12/7 at 84).

Maxwell said he had seen structures in operation with multiple chambers which were basically self-regulating. He said one would have to be built at each diversion structure in order to administer the U.S. claims. He hadn't considered how on-stream reservoirs would be administered, and didn't know how wells would be administered. Weiss also asked how the weirs would work if there were more than one junior right or exchange upstream, meaning one would influence the flow available for the other. Maxwell answered this question by saying the weirs would be designed to make sure the U.S. flows were left in the stream. Weiss then asked if they had "considered the design that would be necessary here to pass sediment to maintain the channels?" Maxwell said these types of problems were not insurmountable, based on 50 years of Forest Service research. He didn't know who would pay for construction of the weirs (12/5 at 141-147).

The judge asked if weirs would be used on diversions built after a priority date of 1898 or a decree date of 1991? Maxwell said water users who had stipulated with the U.S. wouldn't get a structure, but others would. The judge also asked what would prevent the Forest Service from helping a future water user design a diversion under its special permitting authority? Walch said this was a legal question and was an issue of permitting vs. a legal water right (12/10 at 43-50).[9]

Maxwell was also asked about the "quantified proportionately" language in the 1990 claims. The 1990 amendment described the procedure for points

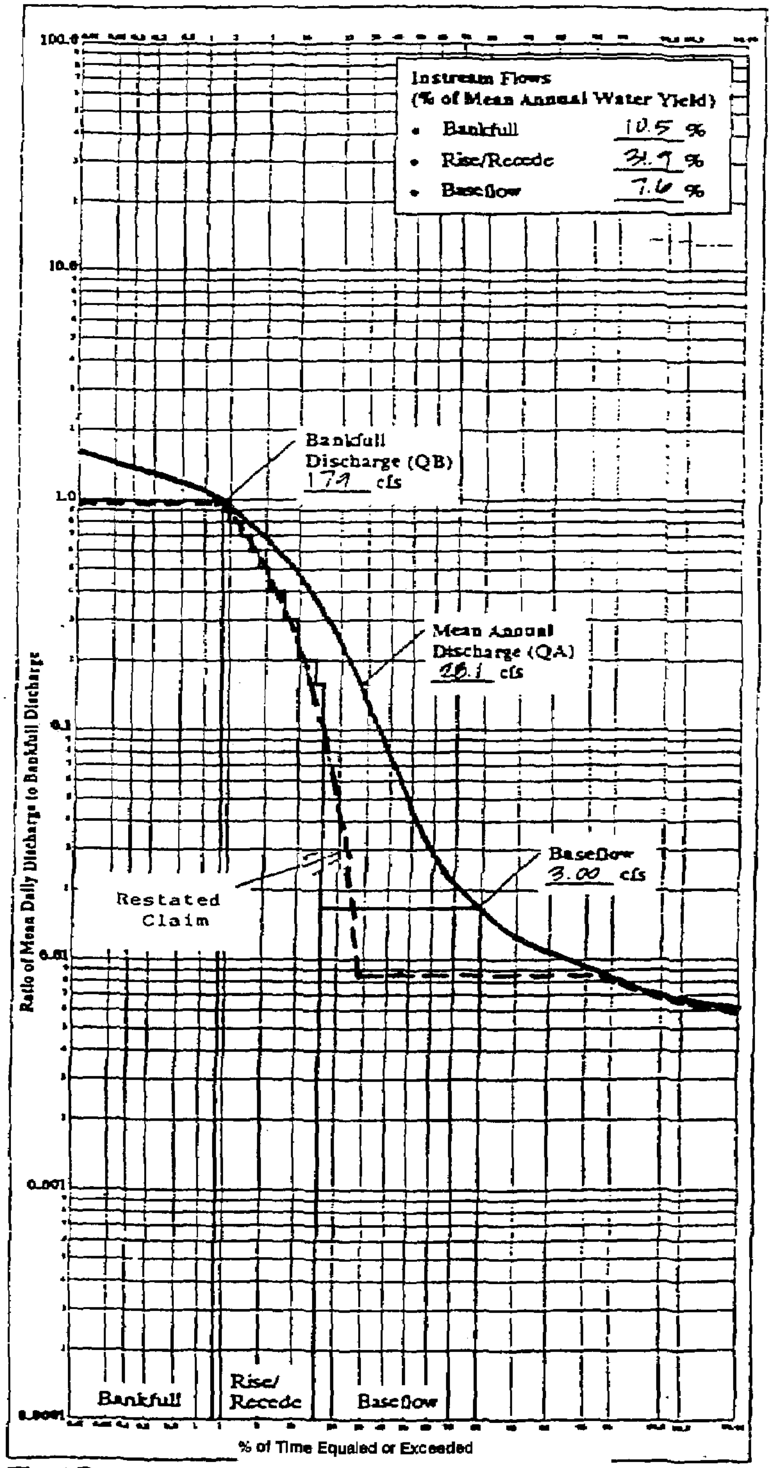
[9] **Author's note:** *a diverter may not actually want - or be entitled to—all of the "excess water" which would be split off to them with a weir. Maxwell never showed a diagram or photograph of the type of weir he had conceptualized.*

USGS Gaging Station
S. St. Vrain Creek near Ward #06-7225

Flow Duration Values for Restated Claim

S. St. Vrain

Class (cfs)	Distrib. (days)	% Time exceed/=	Qn/Qb
179.001	0	0.00%	
179.00	153	1.75%	1.0000
171.00	9	1.85%	0.9553
163.00	16	2.03%	0.9106
155.00	11	2.16%	0.8659
147.00	22	2.41%	0.8212
139.00	25	2.69%	0.7765
131.00	13	2.84%	0.7318
123.00	32	3.21%	0.6872
115.00	34	3.59%	0.6425
108.00	25	3.88%	0.6034
99.60	31	4.23%	0.5564
91.60	28	4.55%	0.5117
83.70	59	5.23%	0.4676
75.70	40	5.68%	0.4229
67.80	58	6.34%	0.3788
59.90	53	6.95%	0.3346
51.90	57	7.60%	0.2899
44.00	102	8.76%	0.2458
37.00	0	8.76%	0.2067
36.00	79	9.66%	0.2011
28.10	159	11.48%	0.1570
25.10	70	12.28%	0.1402
22.20	36	12.69%	0.1240
19.20	69	13.47%	0.1073
16.30	74	14.32%	0.0911
13.30	87	15.31%	0.0743
10.40	145	16.97%	0.0581
7.41	163	18.82%	0.0414
4.46	280	22.02%	0.0249
1.501	500	27.72%	0.0084
1.50	6244	98.96%	0.0084
1.12	62	99.67%	0.0063
0.74	29	100.00%	0.0041
0.00	0	100.00%	0.0000



Flow Duration

Figure 26.—Flow duration curve for the South St. Vrain showing the 1989 and 1990 claimed flows. From Exhibit [A-1625].

other than quantification points as follows (12/5 at 149-150):

> *"For the entire reach of each stream and all its named and unnamed tributaries lying upstream of the respective point of quantification, the United States claims those instream components identified . . . quantified proportionately in a like manner."*

Maxwell said the calculation of a claim at a point of diversion and the building of a weir at that point was consistent with this statement. Weiss asked if the calculation would be based on a claim at a downstream quantification point; e.g. by accounting for evaporation, channel losses, etc. to move the claim upstream, or whether it would be essentially re-calculated using the same procedure as for the QP. Maxwell said he wouldn't want to "shut the door on any reasonable approach to making the claim operational at upstream points," but suggested that it would be done in the same way as for the quantification points (12/5 at 150-153).

The judge said, "in essence, what you are going to do is protect this flow on every inch of the river." This was different from what he understood the original concept to be—and he then asked why the QPs were needed at all. Maxwell said the calculations were done at those points to quantify the instream flows needed for channel maintenance. However, the Forest Service's responsibilities covered the entire channel network, not just the QPs. He said the "quantified proportionately" language connected the QPs with other points upstream (12/10 at 35-42).

Trout cited the example of Trap Creek, where bankfull discharge at a fluvial site had been estimated at 150 cfs; but at a downstream quantification point, the bankfull estimate was 36 cfs. Maxwell said the channel near the quantification point had been severely affected by bulldozer activity. Trout implied that this meant the Forest Service could go upstream from a quantification point and actually obtain a higher bankfull flow rate for the upstream point. Maxwell agreed that this seemed possible (12/10 at 10-12).[10]

[10] **Author's note:** *one could certainly argue whether re-calculating the claim at a diversion point would mean quantifying "proportionately". For example, a lower-elevation quantification point might be related to the low-elevation family of curves, whereas a higher-elevation point on the same stream might be related to a different family of curves. The claims would not necessarily be proportional along the stream. Thus, "quantified in a similar manner" would be better language. Also, what if the quantification methodology changed again in the future? This might mean that a new upstream diversion point would be quantified in a different manner than the original QP. The language should be structured to leave this option open.*

EVALUATION OF THE 1990 CLAIMS AND COMPARISON TO THE 1989 CLAIMS

Maxwell used records from USGS stations to illustrate how the 1989 and 1990 claims looked when superimposed on actual streamflow hydrographs. Figures 23 and 24 are examples. Maxwell pointed out that the static 1989 claim looked the same every year. The 1990 claim was dictated by the flow itself (12/4 at 156-166). According to Maxwell, about 50-70% of the average annual streamflow would be available for diversion or another use under the 1990 claims (12/10 at 43-45).

He also displayed graphs from wet, average and dry years to show that the 1990 instream flow claim was "quite inconsequential" in dry years. In wetter years, the U.S. would claim more but there would also be more available for diversion. Therefore, they would get bankfull in years when it occurred; if it didn't occur, they wouldn't be claiming as much water. Maxwell emphasized the point that the 1989 claims would have taken all the flow in the stream in low-flow years, whereas the 1990 claims would leave some water available for diversion every year. He used the analogy that the 1990 claim was like taking ¼ of the "pint bucket" in a dry year and ½ of the "5-gallon bucket" in a wet year (12/4 at 179-190; 12/5 at 5-10).

The judge made the comment that the diagrams seemed to indicate that there would actually be more water available to diverters in dry years than in wet years. He said, "I was wondering if the traditional farmer's prayer for rain would become a prayer for drought" (12/11 at 32).

Using records from 16 of the USGS base stations, Maxwell compared the 1989 and 1990 claims to the natural flows for each year of record and computed the average annual percentage of flow claimed (by dividing the total claimed amount by the total runoff). For 14 out of the 16 gages, the claimed amount decreased in comparison to the 1989 claim; at the remaining two, it stayed the same. The 1990 claimed percentages ranged from 24 to 56%; the 1989 percentages ranged from 39 to 56% (12/4 at 156-166; Exhibit A-1622).

The judge and opposition attorneys argued that the comparisons were misleading because the 1989 claims were not what would have actually been obtained; they might not have matched the natural hydrograph. They therefore represented the maximum that the U.S. could claim if the claim hydrograph matched the actual streamflow. The 1990 figures represented actual amounts because they had been matched to the streamflow hydrographs (12/4 at 156-170; 12/11 at 109-113). Maxwell did present some figures from 10 USGS gages on what would have actually been obtained by the 1989 claim over the whole period of record:

- 59% of the bankfull volume,
- 73% of rise/recession, and
- 93% of base flow

for a composite average of 80% of the water they intended to claim (12/10 at 50-55).

Weiss pointed out that the 1989 claim had not produced the intended amounts for any of these stations (12/10 at 86-97). The U.S. experts maintained that the 1990 claims would take less water than the 1989 claims, but did not provide adequate comparisons to demonstrate this. Trout used the example of the South St. Vrain, where the 1989 procedure would have obtained 85% of the actual claimed volume on average (about 43% of the average annual runoff). During the wettest year on record, 1957, the 1989 claim would have obtained 98% of the total claimed volume, 10,002 acre-feet. The 1990 claim amounted to 16,767 acre-feet for the same year. Trout showed similar results for other sites. In high years, the U.S. would claim more water with the 1990 claims (12/7 at 69-78; 12/10 at 8-10).

Weiss pointed out that the 1989 claims had a maximum volume in acre-feet which would never be exceeded, whereas the 1990 claims had no such "ceiling." For the South St. Vrain gage, the 1990 claim exceeded the 1989 claim in 9 out of 24 years. For the Little Beaver gage, 6 out of 13 years had higher claims under the new procedure (12/6 at 57-64).

Maxwell said there was no doubt that the 1990 claim would take more water in wet years. He said the new claim "attempts to be dynamic and to be flexible and to adjust to the actual flow in the stream every year, so that in a real wet year we're getting those extra days of bankfull that are needed to offset the zero we're getting in a dry year." He had not actually analyzed the effects of other water rights on how much would be legally available for diversion. However, he said there would be more water available for diversion during dry years and during the rising limbs, and would limit "the level of potential injury to upstream juniors to the lowest practical amount" (12/5 at 15-17; 12/10 at 73-76). Andrews said the 1990 procedure evened out the amount that diverters could reliably depend on—the "firm annual yield." This was essentially the same effect as a reservoir would have, in terms of averaging out the high and low flow years (12/11 at 29-35).

Trout mentioned that the 1989 claim didn't start until May 1, but this provision wasn't included in the 1990 claim. He and Weiss also brought out that the 1990 procedure could result in more than one bankfull claim in one year, including rainfall peaks in the summer. For one example at a USGS station, the "bulk of the hydrograph" occurred in August and September. The 1989 claim would have only encompassed one peak (12/6 at 65-71; 12/5 at 164-178). Trout demonstrated that more than half of the 1990 claims occurred after the 1989 claims in terms of volume; the timing of the claim therefore changed. The 1989 claim had also been based on a fixed number of bankfull days, whereas the new claim could result in a longer bankfull duration. The total duration of the claim increased at several quantification points. Year-round base flows were claimed for at least one site where they hadn't been claimed before (12/6 at 65-78; 12/13 at 41-48).

Weiss said the 1989 claims were intended to quantify a "minimum amount of water necessary to fulfill the primary purposes of the National Forests," yet these claims didn't even achieve that minimum at the gaging stations where it was tested. Under the 1990 procedure, the U.S. would now be claiming more water in wet years and less in dry years. She asked Maxwell which claim, 1989 or 1990, represented the "minimum amount." Maxwell said the 1990 mechanism was a better way of implementing the 1989 claim. The 1989 method was based on averages, but the 1990 claim would match actual flows better on a year-to-year basis. He said the whole period of record had to be considered when evaluating how well the channels would be maintained. Over a period of years, the results would be the same. The judge noted that the question of which claim was the "minimum" was a problem he would have to address (12/6 at 65-78; 12/10 at 86-94).

Andrews also said the 1990 claim would take a similar amount of water, but achieve the U.S.'s objectives somewhat better than the 1989 claims. The 1990 claim would result in a greater number of days of high flows which were important for maintaining channel capacity. However, he still believed the 1989 claim would preserve substantially all of the channel. He wouldn't specifically define a percentage of channel capacity which he would say was "substantially all of the channel" (12/11 at 91-93; 12/10 at 159-161). He said the 1990 claim would maintain the channel essentially as it was at present, with little if any impairment. Because flows above bankfull were not being claimed, sediment transport would be less, but the channel capacity would be maintained (12/11 at 29-32). Andrews also argued that the opposition was being too precise in criticizing the term "**absolute minimum**"; he said it should have been "**adequate minimum.**"

INJURY TO WATER USERS

Altenhofen had testified that many water rights would be potentially affected by the U.S. claims. George Nagy, a Region 2 water rights expert, had analyzed the same records as Altenhofen to determine the impact of the U.S. claims on junior water rights (12/4 at 56-133).

Altenhofen had identified 107 quantification points (QPs) above which there were no junior water rights, and 137 which had junior water rights above them. By the time of the proposed 1990 amended claims, 9 of the original 244 quantification points (QPs) were dropped. Two of those had junior water rights upstream (12/4 at 138-139). Nagy had determined that 164 out of the 235 remaining QPs had no junior water rights upstream; 71 did. The difference between his and Altenhofen's values had to do with settlements made with water users (12/6 at 50-56).

Maxwell said he would recommend that the Forest Service assess the total potential impact of all the upstream junior rights above a QP, and if there was a low risk (e.g. small wells and springs with low consumptive use), then his recommendation would be that the U.S. would not call them out (12/4 at 140-144). Weiss objected to this recommendation because the U.S.'s application was for water rights which could be enforced in Water Court. She said the Court should go on the assumption that the U.S.'s rights would be enforced if granted. Trout also said that under Colorado water law, the senior water rights holder couldn't say which water rights should be called out; this was up to the State which would follow the priority system. The judge let the statement stand, although he said it had been his observation that "good intentions in water matters sometimes evaporate when the need for the water is determined by numero uno" (12/4 at 144-145).

Altenhofen had testified that a total of 1400 water rights would be affected. Walch said there would only be 761 rights affected, 685 of which were wells. The judge said Walch couldn't testify on this, and that Maxwell wasn't qualified to either because he hadn't done the work (12/4 at 145-148).

Maxwell added that the amounts of water claimed varied more from year to year than the amount available for diversion. To him, this represented a "beneficial outcome of this effort." He believed the new methodology would preserve the physical integrity of streams, as well as doing "the job of providing for the legitimate uses" of the forests (12/5 at 42). The judge quizzed Maxwell on the U.S.'s intent in structuring the claims to provide proportionately more water for diversion in dry years than in wet years. He asked whether one of the Forest Service's purposes was to assure extra water to water users. Maxwell said yes. The judge then asked him if it was his view that the term "favorable conditions of water flow" included provisions of water to irrigators. Maxwell said this wasn't his understanding of the Organic Act; the purpose of the claim was to maintain the physical integrity of the stream system. The U.S. was trying to achieve that objective while at the same time providing as much water as practical for diversion. The judge said he had not yet made his "judicial determination of what the term 'favorable condition of water flow' " meant (12/5 at 38-41).

OTHER OPPOSITION CRITICISMS

Altenhofen had questioned whether or not the Forest Service had considered sediment movement when extrapolating from base stations to the quantification points. Troendle used data from the Fraser streams to show how flow dynamics were related to the accumulation of sediment in the weir ponds. Troendle said the amount might or might not be affected by the flow which occurred that year. From flow duration curves, he calculated the duration for which specific flows were equalled or exceeded, and then attempted to correlate these with the sediment accumulations. The regressions weren't very strong, but showed an increase in the R^2 value to a particular discharge, then a decrease. A relationship between annual peak discharge and sediment accumulation was better. In conclusion, Troendle said high levels of flow at relatively long durations were needed to move sediment, i.e. there was a relationship to hydraulics. "The higher and the longer it occurs, the more material we accumulate" (11/29 at 72-85).

Weiss brought out that Troendle couldn't actually tell which flows transported the sediment to the weir ponds because yearly accumulations were measured (11/29 at 85-86). Trout also argued that a regression relationship didn't necessarily show cause and effect; i.e. that a higher level of flow caused an increased amount of sediment. Troendle had said that in a step-pool system, the steps could trap some of the sediment one year, but break down and release it another year. This could cause wide variability about a regression line (12/3 at 34-45).

The U.S. experts had not directly applied their sediment transport analysis in the development of either the 1989 or 1990 claims. Instead, they implied that it was implicit in the claims. The opposers argued that the claims didn't relate to sediment transport or channel maintenance. Angel pointed out that the Parker equation hadn't been used in any way in the 1990 procedures, and that these procedures did not include any site-specific considerations of sediment supplies or transport at the quantification points (12/11 at 38-41).

Troendle made the recommendation that future work should look at the relationship between stream power and particle sizes in the channels, in order to develop relationships which were more theoretical in nature and addressed the ability to move sediment. He said these methods had not yet been developed, and at present the reliance on bankfull discharge was appropriate (12/3 at 104-105).

THE FINAL OUTCOME

In his final decision, the judge denied both the 1990 amendment and the original 1989 claims for channel maintenance flows (see Section 1).

In his decision, he mentioned Andrews' estimated costs of running gaging stations. The judge said he wasn't suggesting that the U.S. should spend over $50 million to obtain an accuracy of plus or minus 5%, but that quantifications which the U.S. had admitted weren't even plus or minus 10% did not permit the Court to determine the precise quantity of water necessary to fulfill the purposes of the National Forest (Decision, p. 29).

He did not consider the 1990 quantifications because they represented a substantial change over the original application. However, he said the U.S.'s claim that the 1990 method reduced the amount of water claimed on average was "virtually an admission that the 1989 claims are not the minimum amount required, at least in certain years and perhaps overall" (Decision, p. 30).

The judge commented that the 1990 procedure had been developed under "hurried time constraints imposed by the pending litigation," which was not the "ideal environment for careful scientific study." He said if his decision was appealed and a new proposal was necessary, that "a proposal developed under calmer and more scholarly circumstances would be appropriate" (Decision, p. 32).

Appendix A. The Cast of Players

FOR THE UNITED STATES OF AMERICA

Attorneys

- Andrew F. Walch
- Lynn Johnson
- John Lange
- Daria Zane

Witnesses

Name	Trial date(s)	Expert in:	Background
Roderick Nash	Jan. 9-10	Intellectual history	Ph.D. American intellectual history; professor U.C. Santa Barbara
Harold Steen	Jan. 10-16	Forest and conservation history	Ph.D. history of conservation; past USFS forester; director for Forest History Society
George Leonard	Jan. 16-17	F.S. policy	USFS associate chief
Gray Reynolds	Jan. 17-18	F.S. policy	USFS director of Watershed and Air Management
Gary Cargill	Jan. 18-22	F.S. policy	USFS regional forester
Richard Madole	Jan. 22-23; Oct. 4; Nov. 13	Scientific geology	Ph.D. geology; worked for USGS 15 years
Luna Leopold	Jan. 23-25	Fluvial geomorphology	Ph.D. geology; USGS chief engineer and scientist; professor U.C. Berkeley; author *Fluvial Processes & Geomorphology*
Loren Potter	Jan. 25-26; Oct. 3-4	Plant ecology	Ph.D. plant ecology; retired professor U. New Mexico
Gordon Jacoby	Jan. 29; Oct. 2-3	Tree ring analysis	Senior research scientist and founder, Tree Ring Laboratory, Columbia U., New York
Hilton Silvey	Jan. 29-Feb. Nov. 14-19	Hydrology	M.S. watershed management; retired USFS regional hydrologist
Lela Chavez	Feb. 5-6	Hydrology	B.S. watershed science; forest hydrologist on Pike NF
Sidney Stuart	Feb. 6	Hydrology	M.S. microbiology; Forest Hydrologist on Arapahoe-Roosevelt NF
Marc Wilcox	Feb. 7	Hydrology	M.S. plant, soil, water science; Forest Hydrologist on Medicine Bow NF, Wyoming
Dave Rosgen	Feb. 7-14	Hydrology (AIH certified)	B.S. forest industries; past USFS forest hydrologist; now stream consultant
Edmund Andrews	Feb. 14-20; Dec. 10-11	Hydrology and fluvial geomorphology	Ph.D. geology; USGS project chief for river mechanics, geomorphology research group
William Gabbert	Oct. 1-2	Hydrology, watershed management, surveying	M.S. watershed management; USFS hydrologist, student
David Dawdy	Nov. 13-14	Hydrology, hydraulics, sediment transport (AIH certified)	M.S. mathematical statistics; retired USGS research engineer, now consultant
Laurel Collins	Nov. 19-21	Fluvial geomorphology (qualitative)	B.A. earth science; district geologist; consultant
Charles Troendle	Nov. 28-Dec. 3	Hydrology and watershed management	Ph.D. forest hydrology; USFS hydrology project leader, Rocky Mtn. Experiment Station
James Maxwell	Dec. 3-10	Hydrology and water management (AIH certified)	B.S. forest watershed science; USFS Region 2 water group leader

FOR THE OPPOSERS

Attorneys

State of Colorado:	Duane Woodward Wendy C. Weiss Marie Sansone Carol Angel	Water Supply & Storage Co., Cache La Poudre, other water associations:	Ward H. Fischer William Fischer
Northern Co. Conservancy:	Robert V. Trout Allison L. Taylor	Big Thompson Ditch Ditch & Mfg.:	Randolph W. Starr
City & County of Denver:	Casey S. Funk Peggy M. Ventura	Public Service Co. of Colorado:	Timothy Flanagan
Red Feather Storage and Irrigation:	Kim R. Lawrence	St. Vrain & Left-Hand Ditch; Upper So. Platte Water Dist.:	Jeffrey J. Kahn

Witnesses

State of Colorado

Name	Trial date(s)	Expert in:	Background
Jeris Danielson	Mar. 19	Water rights, water resources, engineering, hydrology (PE)	Colorado state engineer
George McCarthy	Mar. 19-20		
Stanley Schumm	Mar. 21-27	Fluvial geomorphology	Ph.D. fluvial geomorphology; past USGS geologist; professor at Colorado St. U.; author *The Fluvial System*
Kathleen Cohan	Mar. 27-29	Geology	M.S. geology/hydro/geomorph;hydrogeologist with SLA
Michael Harvey	Mar. 29-Apr. 11; Sept. 18	Fluvial geomorphology and geology	Ph.D. fluvial geomorphology, sedimentology; consultant; citizen of New Zealand
Daryl Simons	Apr. 11-12	Hydraulic engineering, river mechanics (PE)	Ph.D. civil engineering; established SLA; consultant
Richard Harner	June 4-7	Plant ecology	Ph.D. plant ecology; consultant
Edwin Mogren	June 6	Forest ecology	Ph.D. forest ecology; retired CSU professor.
Ruh-Ming Li	June 7	River mechanics, erosion and sedimentation, watershed processes, hydraulic eng. (PE)	Ph.D. civil engineering; president SLA; consultant
Robert Mussetter	June 11-25	Hydrology, hydraulic engineering (PE)	Ph.D. hydraulic engineering; consultant
Alan Berryman	June 25-26	Water resources engineering, water rights admin. in WD1	Division Engineer, Colorado Division of Water Resources
Shawn Hoff	June 26-27		Colorado water commissioner
Mark Curry	June 27-28		Colorado water commissioner
John W. McDonald	June 28	Water resource & development planning, flood plain regulation	Director, Colorado Water Conservation Board

Northen Colorado Water Conservancy Dist.

Name	Trial date(s)	Expert in:	Background
Charles Leaf	June 28, July 30-Aug. 2, 6	Hydrology, water resources engineering, watershed management, channel processes	Ph.D. watershed management; past USFS hydraulic engineer; now consultant
Larry Simpson	July 23-24		General manager, chief engineer, No. Colorado W.C. District
Jon Altenhofen	Aug. 7-8	Water resource and water rights, engineering hydrology. (PE)	M.S. water science and engineering; engineer for No. Colorado W.C. District Northern; 80% of past 2 years spent on WD1 case
Norman I. Wengert	Aug. 9-14		

Cache La Poudre Water Users Assn.

Name	Trial date(s)	Expert in:	Background
Everett Richardson	July 24, Aug. 6-7	Hydraulics, river mechanics (PE)	Ph.D. civil engineering; past sediment/hydraulics researcher with USGS and CSU; now consultant
Elmer Gustafson	July 30		President, irrigation companies
Tom Moore	July 30		President, Water Supply & Storage Co.
Walid Hajj	July 30		Water Resource Manager, Thornton
Robert Stieben	July 30		Manager, Irrig. Co., and president,Cache la Poudre Water Users and Larimer Co. Assns.

Public Service Co. of Colorado

Name	Trial date(s)	Expert in:	Background
Randy Rhodes	July 30	Water resource engineering	

St. Vrain and Left-Hand Ditch Water Conservancy Dist.

Name	Trial date(s)	Expert in:	Background
Robert Brand	Sept. 13-14	Hydrology, water rights, engineering, water resources planning	Degrees in public administration, civil engineering; consulting engineer for St. Vrain/Left Hand

Red Feather Storage and Irrigation Co.

Name	Trial date(s)	Expert in:	Background
George Palos	Sept. 17	Water engineering, hydrology	Engineering consultant for Red Feather Irrig. Co.
Dennis Frydendall	Sept. 17	Lay witness	President, Red Feather Co.
Eugene Barker	Sept. 17	Lay witness	Vice-president, Red Feather Co.

City and County of Denver

Name	Trial date(s)	Expert in:	Background
Steve Dougherty	Sept. 18-19	Ecology	B.S. biology; consultant

Appendix B. Chronology of the WD1 Case

December, 1976: Applications originally filed (no specific quantities claimed).

December, 1977: Applications amended for the first time (separating national forests; still no specific quantities claimed).

1978: U.S. v. New Mexico decision (the "Mimbres decision"). This case defined purposes for which National Forests were reserved under the Organic Act: conserving water flows and furnishing a continuous supply of timber. Reserved water rights were limited to these two purposes.

Summer, 1983: U.S. data collection began.

November, 1984: APPLICATIONS amended for the second time; this included the U.S.'s first attempt to quantify instream flows for channel maintenance. Over 400 quantification points were initially selected. The 1984 claims were made at 271 points for specific quantities of water, in addition to unquantified amounts for fire-fighting and claims for administrative sites.

[**Hiatus** while Jesse case was being resolved. That decision was made **in 1987**, and in it, the Colorado Supreme Court concluded that the U.S. could claim reserved water rights for instream flows to achieve the purposes of the Organic Act.]

September, 1988: Trial date set for April 10, 1989 and later postponed until May. (The U.S. pressed for additional time for another field season and three months extra for data analysis. The Court granted the extension and set the trial date for January 8, 1990.)

January, 1989: U.S. received SLA report from State of Colorado.

October, 1989: U.S. filed further amendments to its applications. Claims were made at 244 quantification points. These claims were for base flow, bankfull flow and a rise/recession component which increased and decreased in a fixed, stepped manner. If the claim exceeded the natural flow, then all of the natural hydrograph was claimed.

January 8, 1990: WD1 trial began.

- **January 8, 1990 to February 20**: U.S. case testimony on legislative history and Forest Service policy to support the theory that channel maintenance flows were one of the purposes of national forests defined by the 1897 Organic Act, and on technical evidence supporting the quantities of water claimed.
- **March 19 to June 25; September 18**: State of Colorado's case history/policy, evidence of injury to existing water users, and technical evidence to prove the amounts claimed by the U.S. were not the minimum amount needed.
- **July 13, 14 and August 3**: Field trips to diversion study sites and quantification points.
- **June 28, July 23, July 30 to August 14**: Northern Colorado Water Conservancy District case.

WD1 trial:

- **July 24 to July 30, September 12 to September 19**: Case for other opposers: St. Vrain and Left-Hand Ditch Water Conservancy District, Red Feather Lakes, Cache la Poudre Water Users Association, Public Service Company of Colorado, and City and County of Denver acting by and through its Board of Water Commissioners.
- **October 1 to December 11**: Rebuttal case for the U.S.
- **November 28**: During its rebuttal case, the U.S. made a motion to file amended applications. These involved quantifications at 235 points, and a "dynamic" claim hydrograph which followed the natural hydrograph in comparison to the 1989 "static" claim.
- **December 13**: Final arguments.

December 21, 1990: The Court denied the 1990 amended applications.

April to September, 1991: Briefs filed on history/policy and technical issues.

March 2, 1992: Closing arguments.

February 12, 1993: Final decision issued.

The U.S. applications for channel maintenance flows were denied. Reserved water rights were granted for fire-fighting and administrative sites.

This chronology is based on information from: Walch, 1/8/90 at 5-35; Weiss, 10/31/90 at 16-19; 2/12/93 Decision; 6/24/92 Memorandum from Marlon Old to Eleanor Towns, and trial schedule.

Appendix C.
Key Word Index

Definitions of key words may be derived from the context in which they are used in the text. Key words have been highlighted on the pages where they are defined.

Key word: page number

Postscript

The judge presiding over the WD1 case displayed an extraordinary degree of patience and perseverance in sitting through a year-long trial which required him to absorb enormous amounts of highly technical information. One witness thanked the judge for his patience, whereupon he replied, "patience is its own reward. That is why they all call me 'kindly old Judge Behrman'." (12/5 at 64). His was often the clear voice of reason in the midst of confusing testimony where it was unclear whether either side was telling "the whole truth," and scientific results provided more controversy than enlightenment. Some of his many comments which interjected humor and perspective into the day to day drudgery of a weighty case have been included in this postscript.

OPENING REMARKS

"You'll notice that up here the flag of the U.S. is to the right of the flag of the State of Colorado." (3/10/89 Hearing, p. 20).

The judge was a stockholder of the Public Service Co. of Colorado, and in a pretrial hearing, said, "if there is any objection, in fact I would be delighted to withdraw. Hearing no objection, I guess it doesn't work this time either." (12/8/89 Hearing, p. 5).

In opening statements, Walch had said he hoped that the decision in this case would be made in 1991, exactly 100 years after the Forest Reserve Act was passed. The judge said he hoped the decision would be "an equally important milestone" (1/8 at 67).

Comments on the Lengthiness of the Trial

"When they publish the book of the Wisdom of Robert A. Behrman, I hope they publish first my observation that the hardest thing to convince a lawyer about a case is that it's over" (9/19 at 192).

The judge often encouraged people to speed up, and on several occasions asked the attorneys to give a "snappy windup" to their cross-examinations. Sometimes when one side was criticizing errors that the others had discovered in their data, the judge said, "this is the pot-callen-the-kettle-black section" and told them to get on with the case.

When cross-examination of one witness had dragged on for a long time over a relatively trivial issue, the judge began to subtly hint that the attorney should put it into higher gear, saying "the kindly old Judge Behrman mode" was going to evaporate (4/10 at 60-61). He had also made the comment, "talking about resistance to flow, I think we have an imbricated case going on here" (4/5 at 43).

He said his term ended January 3, 1993, and the case had to be done by then because he didn't think he'd run for re-election, "particularly after this." (12/8/89 Hearing, p. 65).

". . .so as the Judge sings in 'Trial by Jury,' 'All the legal furies seize you, no suggestion seems to please you, I can sit up here all day, and I must shortly get away'" (12/11 at 54).

Court Procedures

The judge often referred to the water court being "A full-service Court." He said, "we like to provide not only the questions but occasionally the answers" (6/25AM at 42). In applying the same rules to both sides, he said, "this is sauce for the goose and sauce for the gander" (6/25 AM at 107).

Ventura: "I thought a little law might be helpful."

Judge: "That is a low blow. What next?" (11/20 at 28).

The opposition objected to Walch testifying rather than the witness. The court put him on notice and said "never let it happen again, at least not until the next time" (12/4 at 115).

At one point, Angel accused Walch of cutting off the witness's answers, but the judge had not noticed this. He told Walch, "if it is true, don't do that. . .If you are not doing it, continue not to do it, and if you are, stop." The witness then said he had lost track of the question (9/18 at 99).

The judge said several times that he had a record of never turning down "a suggestion for a recess" (11/15 at 51). At the end of one day, the court reporter stated that she was having problems with her machine. The judge then said, "That indicates the Lord wants to terminate or he wouldn't have created that problem," and recessed for the evening (12/4 at 190).

Walch: "May I take the Fifth, Your Honor?"

Judge: "That's a good thought, but it's a little early in the day" (7/25 at 64).

Presenting Technical Testimony

Court:

"We take judicial notice that all estimates made in Water Court are conservative estimates. We have yet, in ten years, yet to have anything but a conservative estimate in this court" (9/19 at 150). Maxwell said something about hobbling himself on the witness stand. The judge said, "the last time that happened was to an engineer who made a non-conservative estimate" (12/6 at 55-56).

The judge several times defended the expertise of witnesses, saying he believed "that academic degrees are not the only path to expertise" (11/19 at 49). "Of course, anybody who says that they are a registered professional engineer, they can generally testify to about anything, and frequently do" (1/22 at 118).

An opposition attorney had criticized Collins' maps as subjective because she had had to draw a line between two substrate types where the border was not clear cut. The judge said that seemed to be "characteristic of this whole field," and that many of the witnesses had said "that's pretty good for geomorphology" (11/20 at 5-7).

Apparently Collins (for the U.S.) looked a lot like Cohan (for the State). The judge made a remark about the State having to do everything the U.S. did, even to the point of producing twins (11/19 at 37-38).

The U.S. spent a considerable amount of time attacking some plan-view maps of diversion sites prepared by the State. The judge made the comment that the Forest Service's data was prepared by forestry people "of unknown qualifications," and that perhaps he should have limited evidence to that presented by fluvial geomorphologists who had published at least 15 books—that it would certainly shorten the trial. He said, "it would be Schumm versus Leopold at 50 paces" (3/29 at 355-367):

"Everybody seems to try to convince everybody else's experts they are wrong, and I don't think anybody has succeeded, but, of course, hope springs eternal" (8/7 at 73-74, 81).

After some discussion on whether snow would melt faster in the sun or not, the judge said, "Sociology was once defined as the science of making the obvious obscure, but I draw no parallels" (11/29 at 156).

The judge asked one witness to explain a graph, "and preferably use words not to exceed three syllables" (12/4 at 20).

Referring to confidence intervals around a mean hydrograph line, the judge asked what the confidence was supposed to mean. He added, for the record, that he had been exposed to a different definition, saying, "Years ago I used to be a deputy district attorney at a time when that was not a full-time job. I got a letter one day. They had a crime—I don't think they have it anymore—called 'confidence game.' This letter said that he wanted me to prosecute this woman for confidence game because he had lived with her and she had thrown him out and he said he had had all the confidence in the world in her" (12/4 at 21).

When Andrews attempted to present 6 journal articles supporting his statements, but said he hadn't made an exhaustive survey of the literature, the judge didn't allow them into evidence, saying, "this was the method of trial known as wager by law. If you swore to something and got twelve people to say they believed you, you could get a verdict. That is no longer in effect . . ." (12/10 at 123).

Several times, the judge criticized the opposition's references to the theories of William Morris Davis, a famous geomorphologist who taught at Harvard as a professor of geomorphology until about 1933, and who developed the idea that a river went through stages of "youth," "maturity" and "old age." Andrews said that Davis's ideas had largely been discredited, and that it was well-known that he made his observations of an area from a train or car. The judge, who had graduated from Harvard, said that he was taught Davis' theories in 1941 and knew they were no longer believed. He added that they did make mistakes at Harvard, but not frequently, "and never in the law school" (2/20 at 125-127; 3/21 at 63).

Commenting on the clinometer which had given the erroneous readings for the State, the judge suggested that maybe the same people developed it as "that Hubbell telescope" (9/18 at 22).

Both sides repeatedly referred to studies done on the Fraser Experimental Forest streams. When Walch referred to a publication by Heede on Deadhorse Creek on the Fraser, the judge said, "nothing like beating a dead horse" (8/2 at 118-123).

On October 1, the judge asked everyone to stand for a moment to honor the fact that they had "broken 1000" on the number of U.S. exhibits. He also said his notes on when the exhibits had been entered were available at 75 cents per page copied or 1.75 per page FAXed. He said, "we are looking forward to it being one of our best sellers" (10/1 at 18).

The 1990 Amendment

After the U.S. had made a proposal to amend their claims and the opposition protested it, the judge quoted the late Senator McCarthy, "This is the most unheard of thing you ever heard of" (10/31 at 40).

Maxwell had said they could thank Altenhofen for pointing out some problems which had helped them upgrade the claim mechanisms. The judge then said, "Mr. Altenhofen, he gets the award of merit" (12/5 at 141). Trout mentioned "Dr. Altenhofen's testimony"—the judge said he was sure Mr. Altenhofen appreciated the honorary degree (11/28 at 152-153).

Maxwell had pointed out some problems with the spreadsheet used for calculating bankfull discharges. The judge said, "Perhaps this is an example of a situation I have noticed. As a Judge, I have noticed that lawyers don't ever make any mistakes, but their secretaries make them all the time" (12/6 at 22).

After finding he had only made two mistakes in recording which exhibits had been entered, he said, "I can't resist. That puts me ahead of the Forest Service and also the State of Colorado, if I may say so" (12/5 at 87).

The judge made this comment about the U.S. claims: "in the words of the late Justice Jackson, to a certain extent, the more he explained it to me, the more I don't understand it" (12/10 at 40).

FINAL REMARKS

The judge made the comment that this field of science was developing rapidly. If that were true and the Court concluded that federal reserved water rights did exist and were necessary, he wondered if they could just wait awhile and let science develop a much simpler method than the "cumbersome" one proposed by the U.S. for quantifying their claims (12/4 at 53-54). He said, "it will be the Court's determination as to whether" the U.S. claims would maintain the channels or not. "Whether I am correct or not will be determined by judges of appellate courts who will probably know less about fluvial geomorphology than I do" (12/5 at 122-123).

Judge Behrman ended by saying, "But, if I may say so, this has been an extremely interesting case. I think somewhat over-long; I think, to be honest with you, somewhat longer than it really had to be, but it has certainly been educational, I'll say that, and enjoyable some days. But, in general, I think it has been very interesting" (12/11 at 118).

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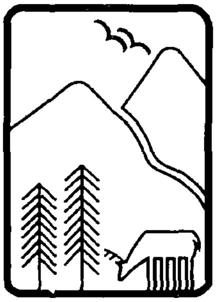
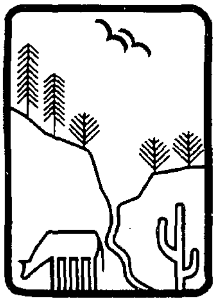
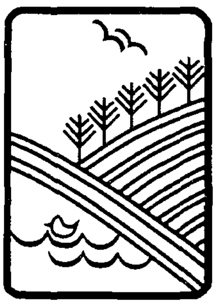
Rocky Mountain Forest and Range Experiment Station



Rocky Mountains



Southwest



Great Plains

The Rocky Mountain Station is one of seven regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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